Environment Canada Environnement Canada

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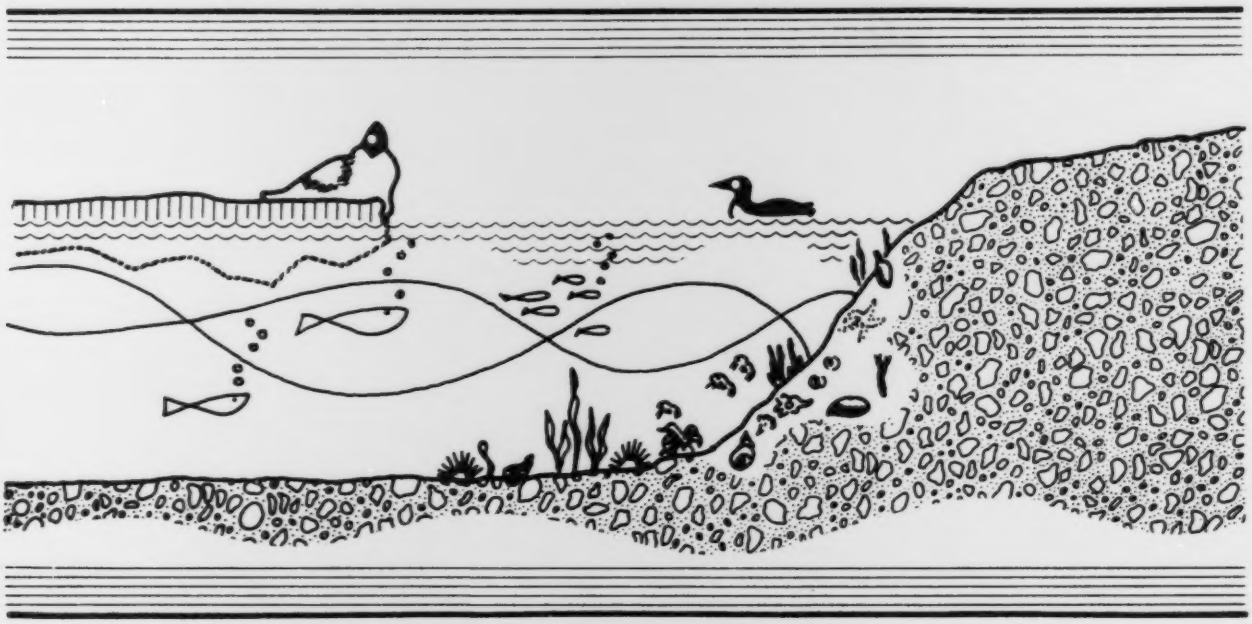
QH 91.8.04 W67
VOL ISS 81-1
WORKING REPORT SERIES (BAFFIN ISLAN
D OIL SPILL PROJECT (CANADA))

CHEMISTRY

1. Field Sampling and Measurements



Baffin Island Oil Spill Project

WORKING REPORT SERIES

1981 STUDY RESULTS

The Baffin Island Oil Spill Project

OBJECTIVES

The Baffin Island Oil Spill (BIOS) Project is a program of research into arctic marine oil spill countermeasures. It consists of two main experiments or studies. The first of these, referred to as the Nearshore Study, was designed to determine if the use of dispersants in the nearshore environment would decrease or increase the impact of spilled oil. The second of the two experiments in the BIOS Project is referred to as the Shoreline Study. It was designed to determine the relative effectiveness of shoreline cleanup countermeasures on arctic beaches.

The project was designed to be four years in length and commenced in 1980.

FUNDING

The BIOS Project is funded and supported by the Canadian Government (Environment Canada; Canadian Coast Guard; Indian and Northern Affairs; Energy, Mines & Resources; and Fisheries & Oceans), by the U.S. Government (Outer Continental Shelf Environmental Assessment Program and U.S. Coast Guard), by the Norwegian Government and by the Petroleum Industry (Canadian Offshore Oil Spill Research Association; BP International [London] and Petro-Canada).

WORKING REPORT SERIES

This report is the result of work performed under the Baffin Island Oil Spill Project. It is undergoing a limited distribution prior to Project completion in order to transfer the information to people working in related research. The report has not undergone rigorous technical review by the BIOS management or technical committees and does not necessarily reflect the views or policies of these groups.

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Correct citation for this publication:

Green, D.R., Humphrey, B., and Fowler, B., 1982, Chemistry: 1. Field Sampling and Measurements - 1981 Study Results. (BIOS) Baffin Island Oil Spill Project Working Report 81-1: 111 p.

File R-16-4

BAFFIN ISLAND OIL SPILL PROJECT
CHEMISTRY COMPONENT

REPORT ON THE 1981
OIL SPILL EXPERIMENTS

VOLUME 1
SUMMARY OF FIELD WORK

Final Report
Contract No. OSS81-00086

Prepared for

Environment Canada
Environmental Protection Service
Edmonton, Alberta

by

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MAY, 1982

EXECUTIVE SUMMARY

During the 1981 summer field season, three oil spill experiments were undertaken at the B.I.O.S. Cape Hatt site: a 200 m stretch of shoreline was oiled for testing various shoreline countermeasures, and two major near-shore oil spills were conducted, one of which was dispersed and one left as a surface oil spill. This report is the first of two volumes dealing with the chemistry program. It summarizes the field sampling work and the field measurements of total oil concentrations in water and in beach sediment. Volume 2 presents detailed compositional analyses of sediment, water and tissue samples performed in laboratories at Energy Resources Co., Cambridge, Mass.

Field measurements of total oil in beach sediments were made for the various spills by an infrared method. These measurements were used in assessing the effectiveness of shoreline countermeasures, in estimating natural erosion of oil from the beach, and in determining an oil 'budget' for the near-shore spills.

Oil concentrations in the water column were measured with an array of flow-through fluorometers. The fluorometry instrumentation allowed the movements of the dispersed/dissolved oil to be tracked in real time, and provided a continuous monitor of the exposure of benthos to oil. For the dispersed oil spill, 36 hour benthic oil exposures averaged 300 ± 100 ppm-h in the experimental bay. Maximum concentrations were about 50 ppm, except immediately adjacent to the diffuser pipe where concentrations reached 160 ppm. In contrast, for the surface spill, oil could not be detected below 1 m depth. Benthic exposures were therefore below the detection limit of 0.25 ppm-h.

For the surface oil spill, virtually all of the spilled oil was either on the beach or was collected by mechanical means. Evaporation was the dominant weathering process. For the dispersed oil spill, nearly all of the oil remained in the water column and dispersion was the dominant weathering process. The chemical dispersant was very effective at promoting dispersion and preventing oil from reaching the shoreline.

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ACKNOWLEDGEMENTS

We especially would like to acknowledge the very substantial contribution of Dr. Walter Cretney, Institute of Ocean Sciences, Sidney, B.C., who devoted a great deal of his time and energy to the B.I.O.S. chemistry program. His advice was often sought and was always useful and well-informed.

We were assisted in the field by David Hope, of Seakem, and David Fiest, of Energy Resources Co. We thank them for their good humour and hard work through the long days of monitoring, sampling, and laboratory work at Cape Hatt.

For assistance back in Victoria we thank Mitzi van Zinderen Bakker for laboratory analyses, Sandra Budac and Valerie Forsland for drafting, and Pat Rothwell for word processing. Peter Berrang, David Thomas and Gary Sergy reviewed the manuscript.

1. INTRODUCTION

The experiments at Cape Hatt during the summer of 1981 consisted of a series of shoreline oil spills for testing various beach countermeasures, followed by two major near-shore spills designed to assess the wisdom of using dispersants on offshore oil spills in the Arctic. The first of the near-shore experiments was a surface oil spill in which 15 metric tons of oil were released from a spill plate in Bay 11 (see Figure 1.1) on 19 August. This was followed on 27 August by a dispersed oil spill, which was generated by mixing 15 metric tons of oil with 10% dispersant and pumping the mix out a diffuser pipe laid along the bottom of Bay 9.

For the chemistry program five people were in the field for the period 6 August to 2 September with one staying until 21 September to assist with post-spill sampling. The goals of the field work were:

1. To sample water, sediment and tissue prior to the spills to determine the hydrocarbon baseline levels.

2. To provide total hydrocarbon measurements in the field for the shoreline oil spills so that the effect of countermeasures could be determined, the natural erosion of oil from the beach measured, and a budget for the spilled oil prepared.

3. To provide real-time tracking of oil in the water column so that the eventual fate of the dispersed/dissolved oil could be determined.

4. To provide continuous monitoring of oil concentrations in the bottom waters of the experimental bays, so that the exposure of the benthos to oil could be measured.

5. To collect an extensive suite of water, sediment and organism samples during and immediately after the near-shore spills, and again one month after, to determine the fate of the oil and its concentration in various types of benthic organisms.

The monitoring of oil concentrations was accomplished with a unique array of flow-through fluorometers. Much of this report deals with the voluminous data collected from the fluorometry systems, which were very effective in providing a continuous monitor of oil concentrations in the experimental bays, and reasonably effective at tracking the movements of the dispersed oil cloud.

Volume 2 of this report deals with the extensive analytical work done on the water, sediment and tissue samples collected at Cape Hatt. The goals of this analytical program were to establish the transport paths, fate and weathering of oil from the spills.

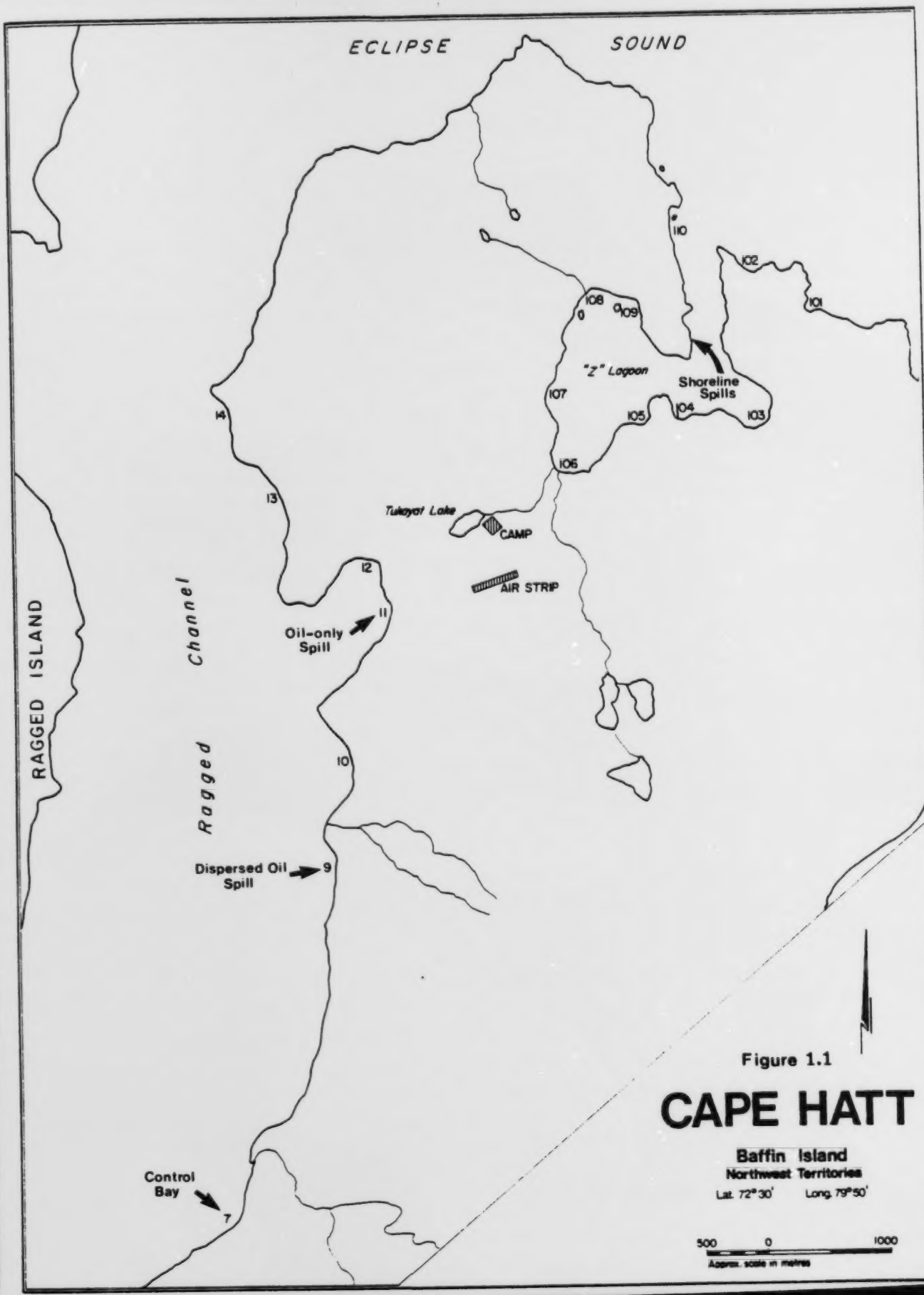
ECLIPSE SOUND
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Figure 1.1
CAPE HATT
Baffin Island
Northwest Territories
Lat. 72°30'
Long. 79°50'
500 0 1000
Approx. scale in metres

2. INSTRUMENTATION AND METHODS

2.1 Field Fluorometry

The successful execution of the near-shore oil experiments, particularly the dispersed oil experiment, depended on being able to track the movement of the dispersed oil. This real-time tracking of the oil movements was accomplished by the use of flow-through fluorescence instrumentation. Five instruments were deployed for the dispersed oil spill:

1. Two fluorometers were set up in tents on the beach. For each of the two shore stations, three submersible pumps, placed at nominal depths of 3, 7 and 10 m, pumped through half-inch polyethylene tubing to a manifold on the shore and then to a flow-through fluorometer. The manifold allowed the operator to select which of the three bottom pumps he wished to monitor.

2. A third flow-through fluorescence system was deployed on a raft in the centre of the experimental area. This instrument monitored four separate pumps located at 0, 2, 4 and 6 m depths. Again a manifold was used so the operator could select the depth he wished to monitor.

3. A fourth flow-through fluorometer was placed on a launch and used to obtain vertical profile data by lowering and raising a submersible pump and tubing.

4. A towed submersible fluorometer, called a Petrotrack, was used to obtain horizontal profile information in the experimental areas. It could be towed horizontally at a speed of up to 8 kts.

The pumps used were either Teel epoxymagnetic submersible pumps model 1P681A or Little Giant submersible pumps model 3E 12WDVR. The valves were 3-way Kitz 1/2-400, brass and steel.

All five of the fluorometers were Turner Designs Model 10-005. All instruments were equipped with a filter system designed for detecting the soluble aromatic fraction of the dispersed oil. The characteristics of the excitation and emission filters for the instruments, together with the excitation and emission spectra for Lagomedio crude oil are shown in Figures 2.1-2.3.

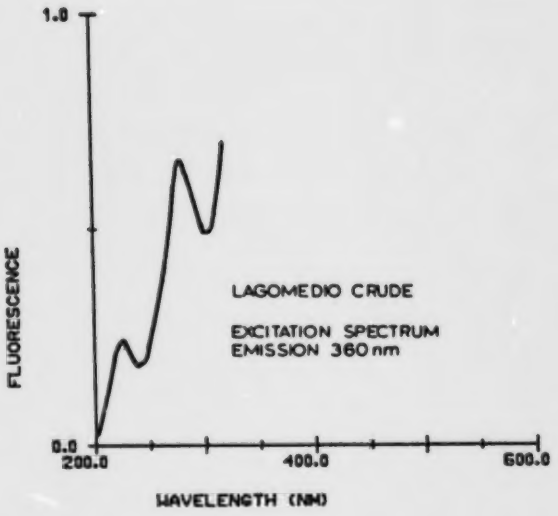


Figure 2.1 The Fluorescence Excitation Spectrum of Lagomedio Crude Oil

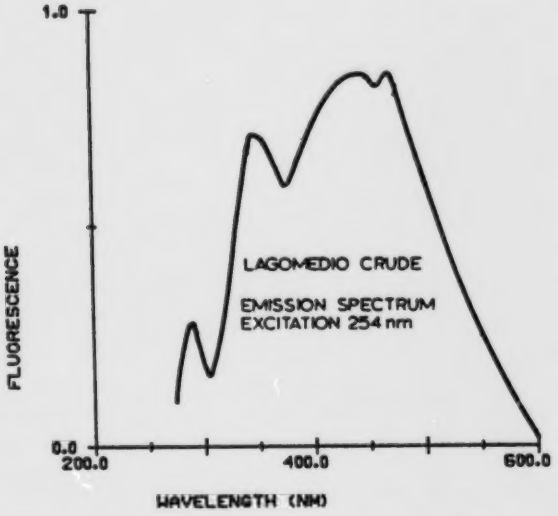


Figure 2.2 The Fluorescence Emission Spectrum of Lagomedio Crude Oil

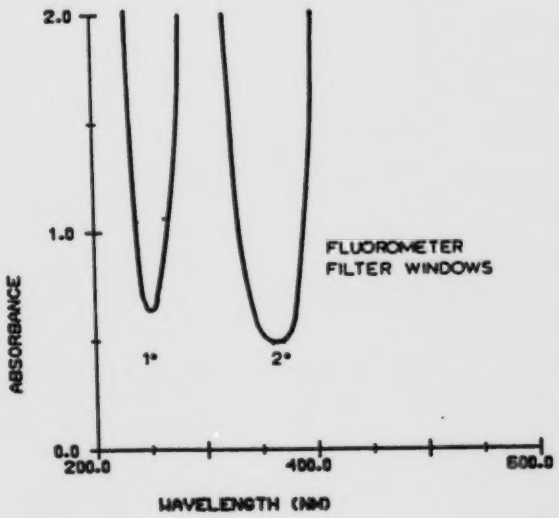


Figure 2.3 The Excitation and Emission Bandwidths of the Filters used for Oil Detection in the Flow-through fluorometers

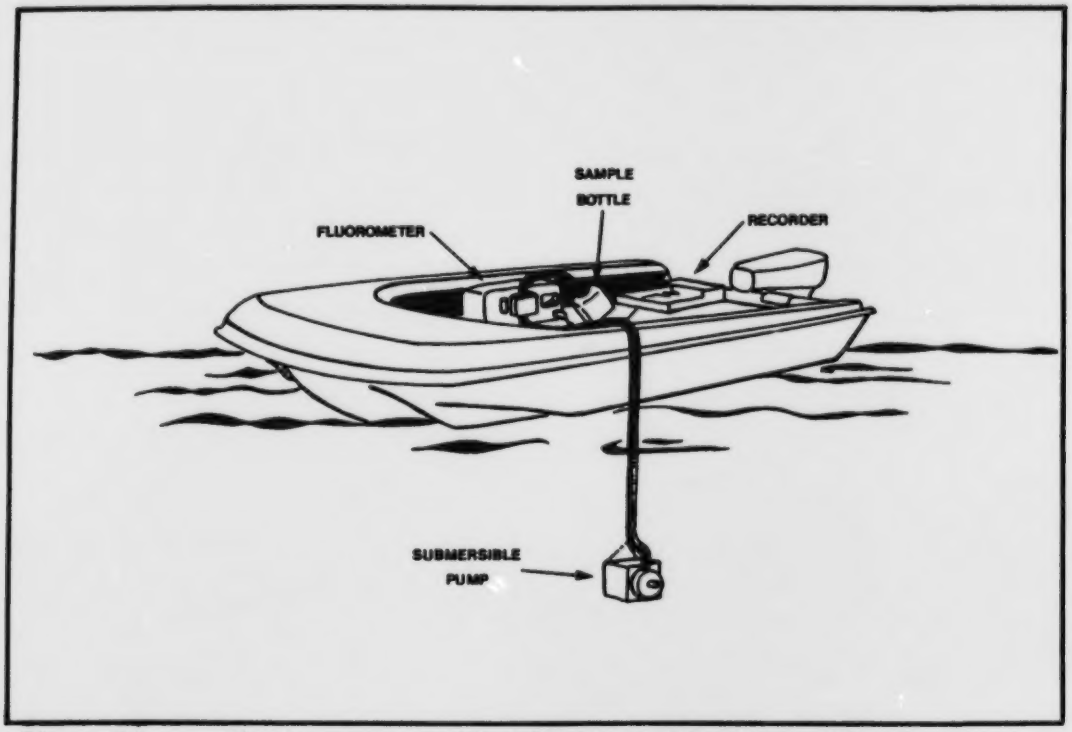


Figure 2.4 The Arrangement Used for Vertical Profiling with a Flow-through Fluorometry System.

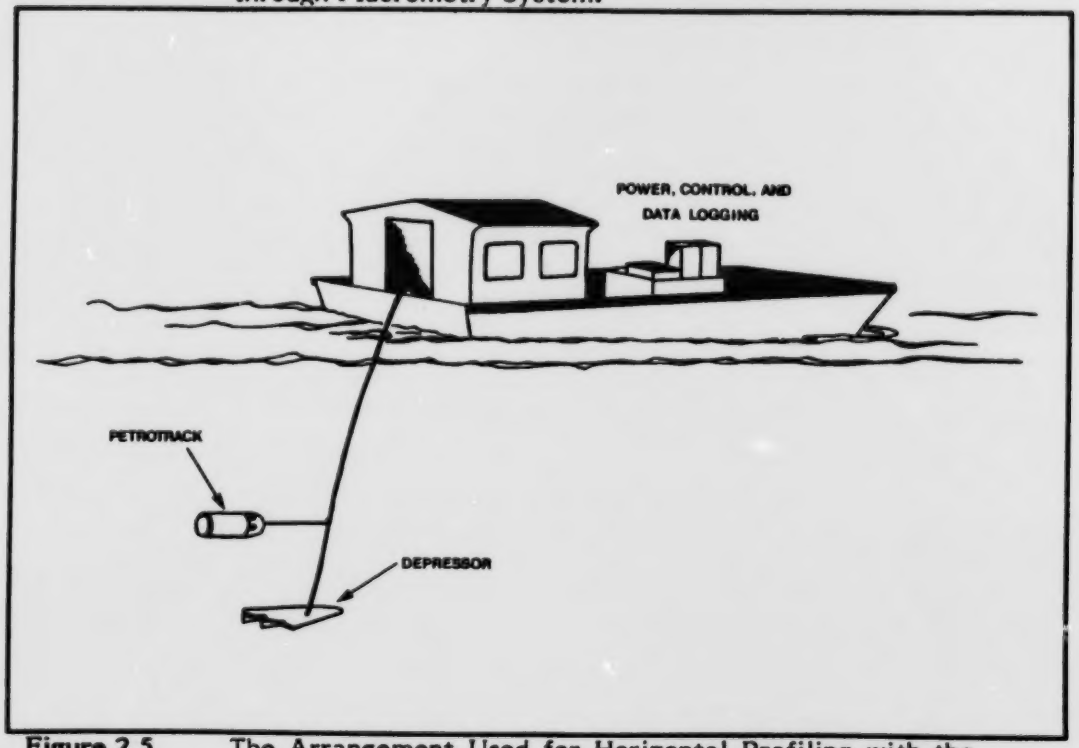


Figure 2.5 The Arrangement Used for Horizontal Profiling with the Towed Underwater Fluorometer (the Petrotrack).

2.2 Positioning

The accurate mapping of oil spill movements in the two near-shore oil spill experiments required the use of a positioning system. A Motorola R.P.S. positioning system, which provided ± 5 m accuracy within the experimental areas, was deployed. The system was used primarily to position the Petrotrack continuous monitoring submersible fluorometer. It was also used to position various buoys, the shoreline, the transects and the diffuser pipe. In this way an accurate map was prepared of each of the experimental bays and the equipment deployed therein.

2.3 Analytical Methods

2.3.1 Analysis of Water Samples for Total Hydrocarbons

Introduction

In order to compare the results of the flow-through fluorescence systems with standard laboratory analyses, approximately one hundred validation samples were taken from the fluorometer outflows. These 1L samples were extracted at Cape Hatt and the extracts shipped to Seakem for analysis by both infra-red and fluorescence techniques.

Cleaning Procedures

Freon 113 (1,1,2,-trichlorotrifluoroethane, BDH, 'distilled in glass' grade) and hexane (BDH, UV grade) were distilled through a prebaked 80 cm raschig-packed column, taking a 5% to 85% cut. Acetone, dichloromethane, and methanol (BDH or Caledon, distilled in glass) were used as received.

Glassware, including sample bottles, was cleaned with warm water and detergent, rinsed with distilled water and baked overnight at 300-350°C. Openings were then covered with baked aluminum foil until immediately prior to use. Glassware used repeatedly at Cape Hatt could not be baked prior to each use and was rinsed with solvent and air dried. Teflon sheet (FEP, 0.002 in), used for bottle cap liners, was cleaned with chromic acid, air dried and soxhlet-extracted overnight with dichloromethane. Glassware used in the fluorescence analysis was rinsed with hexane immediately prior to use.

Sodium sulphate (granular, anhydrous, Mallincrodt) was baked overnight at 350°C.

Extraction Procedure

The validation water samples (800 - 850 mL) were extracted in the 1L sample bottles with freon 113 (20 mL) by shaking vigorously for 2 minutes in a shaker (approximately 300 oscillations min^{-1}). After standing 10 minutes, the freon extract was transferred with a 25 cm disposable glass pipette to a 100 mL glass

storage vial with a teflon lined cap. The extraction was repeated with two additional 20 mL portions of freon 113.

After extraction the water sample was transferred to a 1L graduated cylinder and the sample volume determined. The extracts were stored at 4°C in the dark and shipped south for analysis at Seakem.

Infra-red Analysis

A subsample (~ 2g) of the freon extract was taken from close to the bottom of the vial so as to be essentially free of water and placed on 50 mg anhydrous sodium sulfate in a 4 mL teflon capped vial then allowed to stand for 10 minutes. The infra-red cell was rinsed with 2 x 300 µL of the extract using a pair of 1 mL glass syringes and then the cell completely filled with sample (300 µL).

The infra-red analyses were performed on a Perkin- Elmer 457 instrument at the Institute of Ocean Sciences by permission of Dr. W.C. Cretney and at Seakem using a Perkin-Elmer 337. Both are double beam grating instruments. Sodium chloride solution cells with 1.0 mm path length were used. Samples were scanned from 3300 to 2700 cm^{-1}, the region of interest at 3000 cm^{-1} to 2800 cm^{-1} being scanned at 100 $cm^{-1}.min^{-1}$. The methyl C-H stretch at 2930 cm^{-1} was used for quantification and each spectrum calibrated with a 2850.7 cm^{-1} peak from 0.1 mm polystyrene reference film.

The infra-red instrument and cells were calibrated with standard solutions of dried Lagomedio crude taken from the bay 11 storage pool (19 August, 1981) gravimetrically diluted with freon 113. A calibration curve was drawn for each cell over a range of 50 to 1200 ppm, with a detection limit of 20 ppm in the extract.

UV Fluorescence Analyses

A subsample (approximately 20 g) of the freon 113 field extract was weighed into a freon-rinsed, dried 100 mL round-bottom flask. 3 x 40 mL hexane was added and the volume reduced (x 3) to 10 mL on a rotary evaporator. The hexane extract, now free of freon, was quantitatively transferred to a tared quartz cuvette, reweighed and the fluorescence promptly recorded. Extracts for which the fluorescence exceeded the calibrated fluorometer range were gravimetrically diluted with hexane and the fluorescence redetermined.

Analyses were carried out using a Turner Designs 10-005 fluorometer with short wavelength filters for oil detection (254 nm excitation, 365 nm emission) and a 25 mm o.d. quartz cuvette. The same filters and cell material were used in the field oil monitoring. The detection limit for the system, limited by the blank, was 10 ppb oil in the extract, which corresponds to a concentration of 1 ppb or less in the seawater sample.

Standards were prepared gravimetrically using Lagomedio crude in hexane. Eighteen standards covering the concentration range from 0.010 ppm to 50 ppm were used.

All fluorometer meter readings were converted the 100 x 3.16 scale units and the blank value for the current batch of hexane subtracted to give the reported net fluorescence values. Concentrations were determined graphically from the calibration curve.

2.3.2 Analysis of Beach Samples for Total Hydrocarbons

Introduction

In excess of three hundred beach samples were collected from the shoreline spill plots for total hydrocarbon determination. Smaller sets of samples were collected from the beaches of Bays 9 and 11 where the nearshore spills took place. In order to reduce sampling-induced variability, large samples (circa 1 kg) were extracted, and compositing of samples was done where possible.

Cleaning Procedures

Technical grade carbon tetrachloride was distilled and extraction jars were rinsed several times with solvent and air-dried prior to use. More rigorous cleaning procedures were not required because of the high levels of hydrocarbons present and the relative insensitivity of the analytical method.

Extraction Procedure

Samples, which were stored frozen, were allowed to thaw, and 4 x 500-800 g samples (usually) were weighed into a tared 1L wide-mouth Teflon jar. The original sample containers were rinsed with 20 mL each of solvent and the rinse solvent plus an additional 80-200 mL solvent were weighed into the Teflon jar. The jar was tightly capped with a leak-tight screw lid, vigorously shaken for 5 minutes with a mechanical shaker, and a 4 mL aliquot of the extract taken for analysis.

Analysis

The extracts were dried over 50 mg anhydrous granular sodium sulphate and analyzed by infra-red spectroscopy either at Cape Hatt or at Seakem on Perkin-Elmer instruments with 1 mm path length sodium chloride cells. The peak intensities were normalized against a standard (1200 ppm) for which the 2930 peak height was determined immediately after each sample was run. This was necessary to minimize errors due to sensitivity changes of the field instrument.

The normalized peak heights were compared to a calibration response curve of Lagomedio crude in carbon tetrachloride to give the oil concentration in the extract. Aliquots were diluted gravimetrically to the working concentration range. The detection limit was estimated at 20 ppm.

3. SAMPLING PROGRAM

3.1 Introduction

The sampling program at Cape Hatt for both the offshore and the shoreline experimental spills was extensive. For the shoreline spill, over three hundred beach samples were collected for total hydrocarbon measurement and sixty for gas chromatographic analysis. The sampling program is summarized by Owens et al., 1982, and will not be duplicated here.

The near-shore oil spills involved a much more varied sampling program that included water, sediment, sediment traps and floc, and a variety of organisms. The full summary of types of samples collected is listed in Table 3.1. The methods by which the samples were collected are summarized in Section 3.2 and the sampling strategy in Section 3.3. Further details of this portion of the sampling program can be found in Boehm et al., 1982.

TABLE 3.1

NEAR-SHORE OIL SPILLS:

SUMMARY OF TYPES OF SAMPLES TAKEN

GENERAL TYPE	DESCRIPTION	COLLECTION METHOD	LOCATION OF SAMPLES
Water	Volatile hydrocarbons (200 mL)	pump	ERCO[a]
	Calibration (1 L)	pump	SEAKEM[b]
	High molecular weight hc (4 L)	pump/NBS	ERCO
	Large volume water samples (50 L)	special device	ERCO
Sediment	Floc	filter/pump	ERCO
	Surface sediment-tissue plots	diver/jar	ERCO
	Surface sediment-biology transects	diver/jar	ERCO
	Sediment traps	cylinder	ERCO
	Beach sediment (Bays 9 and 11)	hand-collected	SEAKEM/ ERCO
Tissue	Mya truncata - bivalve	diver/	BATELLE[c]
	Strongylocentrotus droebachiensis - urchin	hand-collected	CWS[d]
	Macoma calcarea - bivalve		ERCO
	Macoma moesta - bivalve		ERCO
	Serripes groenlandica - bivalve	diver/	BATELLE
	Nuculana minuta - bivalve	air-lifted	ERCO
	Astarte borealis - bivalve		BATELLE
	Astarte montagui - bivalve		ERCO
	Pectinaria grandulosa - polychaete		CWS
Oil	Oil from reservoirs	jar	ERCO
	Oil from diffuser pipe	jar	ERCO
	Surface oil slicks	jar	ERCO

a ERCO: Dr. P. Boehm, Energy Resources Co., Cambridge, MA, U.S.A. (617 661-3111).

b SEAKEM: Dr. D. Green, Seakem Oceanography Ltd., Sidney, B.C. (604 656-0881).

c BATELLE: Dr. G. Neff, Batelle, Boston, MA, U.S.A.

d CWS: Dr. R. Englehart, Department of Indian and Northern Development, Ottawa, Ontario (819 997-0044).

3.2 Sampling Methods

3.2.1 Water Sampling

Volatile Hydrocarbon Samples

200 mL water samples were collected in beer bottles and immediately capped with no air space. These samples were preserved with mercuric chloride and kept cool for analysis by a gas chromatographic method to determine the light hydrocarbon components, C-6 to C-10 +. The samples were obtained from the pump systems used for the continuous fluorometry monitoring. In obtaining these samples, care was taken to avoid contamination from hydrocarbon vapours from outboard motors or generators.

High Molecular Weight Hydrocarbon Samples

4 L water samples were collected both by the pumps used for the continuous fluorometry and by the National Bureau of Standards sampler (see Figure 3.1). These samples were extracted in the field and the extracts taken south for analysis by gas chromatography and by gas chromatography-mass spectrometry.

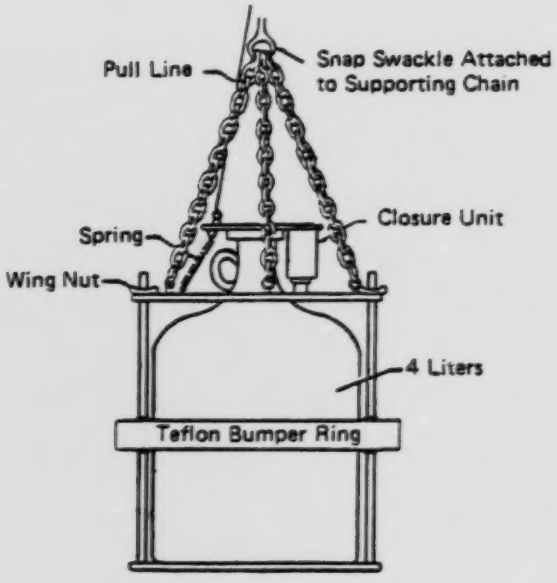


Figure 3.1

The National Bureau of Standards Water Sampler (The spring-loaded lid has a Teflon-wrapped rubber stopper to seal the sampler from contamination during deployment and recovery.)

Large Volume Water Samples

In order to obtain better measurements of very low levels of hydrocarbons in the water column, a large volume water sampler was used. This device relied on the extraction capability of polyurethane foam to extract hydrocarbons from the water column. For each sample an average of 60 L was pumped through a glass fibre filter and polyurethane foam giving an integrated sample over approximately three hours. The sampler is shown schematically in Figure 3.2.

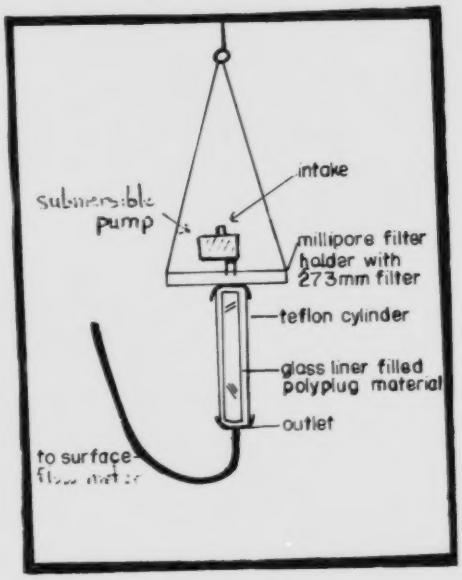


Figure 3.2

The Large Volume Water Sampler

Validation Samples

In order to validate the flow-through fluorometry systems used in tracking the oil clouds and providing real-time data at the spill site, 1 L validation samples were collected from the fluorometer effluents. These samples were extracted at Cape Hatt for analysis in the south by both infra-red spectroscopy and fluorometry. The results obtained were compared to the oil concentrations indicated by the fluorometers at the time of sampling.

3.2.2 Sediment Sampling

Hand Sampling

Most of the sediment samples collected in the experimental areas of the two oil spills were collected by divers using jars. The divers collected samples in 16 oz glass jars that were scraped along the surface of the sediment collecting the top 2-4 cm of sediment. Jars were capped under water, brought to the surface and frozen for analysis in the south. A set of samples was taken from along the two biology transects in each bay. A second set of sediment samples was taken from the tissue plots. Each tissue plot location was sampled in triplicate. The sediment samples were analysed by synchronous UV fluorescence and a selection of the samples was analysed by gas chromatography/mass spectrometry.

Sediment Traps

Before, during and after each of the two near-shore oil spills, sediment traps were deployed in the experimental bays. The sediment traps were PVC cylinders (11 cm diameter x 50 cm length) with baffles which stood on platforms on the bottom. Inside the cylinders were collection jars which were changed after approximately a three day collection period. The sediment trap sampling schedule is summarized by Boehm et al., 1982, p. 31.

Floc Sampling

In planning for the oil spill, it was predicted that most of the oil in the sediments would occur in the light, recently-sedimented flocculent material. We therefore designed a sampler to vacuum this material off the bottom (see Figure 3.3). The sampler consisted of a submersible pump which vacuumed an area of about 0.3 m^2. The flocculent material was filtered onto GFC filters which were removed after each sampling, frozen, and shipped south for analysis.

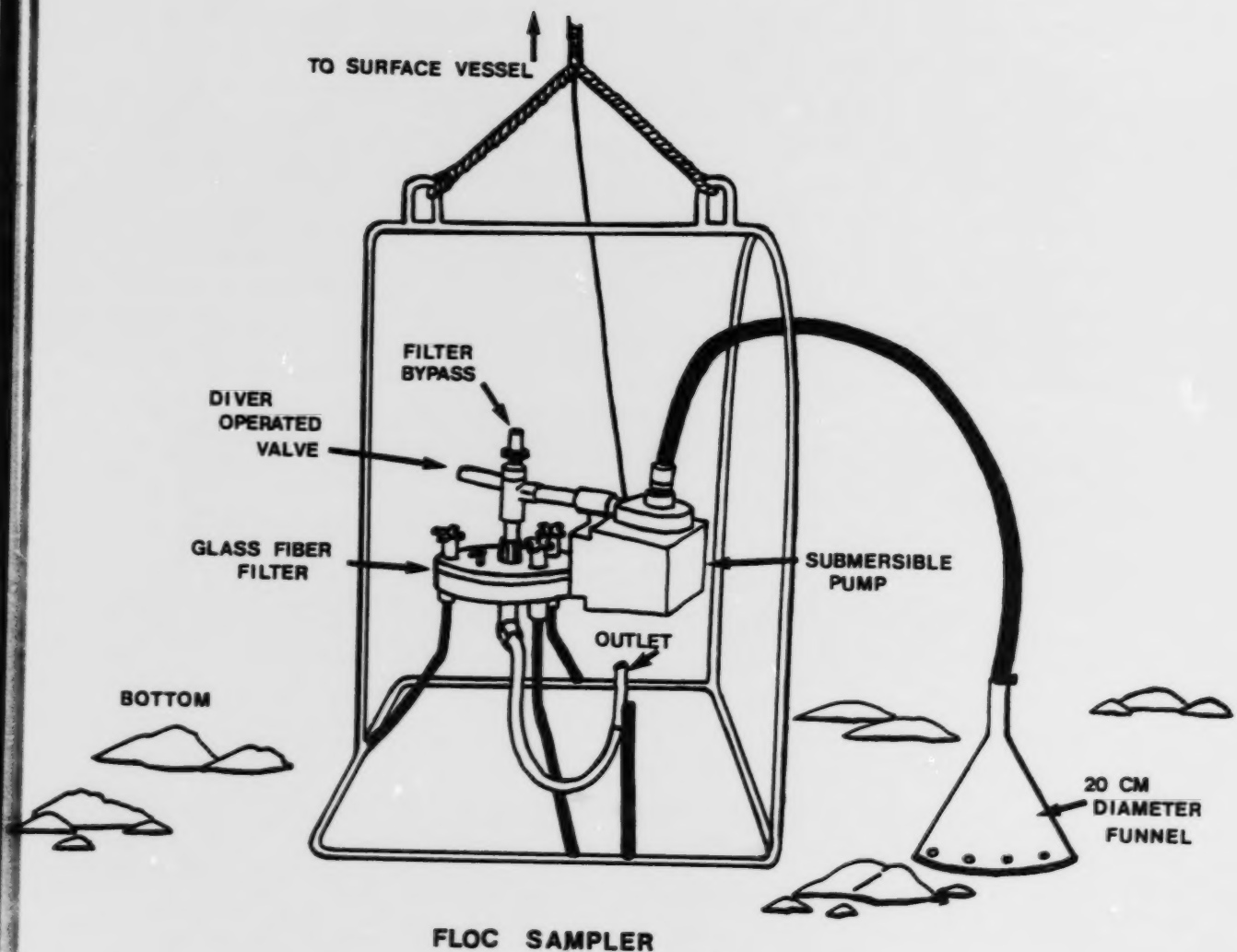


Figure 3.3 The 'Floc' Sampler for Vacuuming Recently-sedimented Flocculent Material from the Ocean Bottom.

3.2.3 Beach Sediment Sampling

Since much of the oil in the oil-only experiment and some oil in the dispersed oil experiment ended up on the beach, it was necessary to sample the beach in a reasonably quantitative manner in order to obtain a material balance for the quantity of oil spilled. For the oil-only spill, transects were laid out on the beach and sampling was conducted one day, one week and three weeks after the spill from a number of sites on each transect. In the dispersed oil spill, where the quantity of oil on the beach was obviously very small, the sampling program was more modest. In all cases, the samples were hand-collected in hydrocarbon-cleaned glass jars. The detailed sampling program is summarized by Owens et al., 1982.

3.2.4 Tissue Sampling

Divers collected a total of 9 different species from the experimental areas. Of these, seven were bivalves, one was a sea urchin, and one was a polychaete. The urchin and the bivalve Mya truncata were hand-collected by the divers. The smaller and more deeply buried organisms were collected by air-lift. Samples which were collected for histopathological analysis were preserved using formaldehyde. Samples which were collected for chemical analysis were preserved by freezing.

3.2.5 Oil Sampling

It was suspected that the oil which was used in the near-shore oil spill experiments was not entirely consistent from barrel to barrel. Therefore, samples were taken periodically for analysis to determine the chemical composition of the oil which was applied to the experimental areas. These samples were taken by dipping jars in the reservoirs or taking samples from the diffuser pipe. In addition, some samples were taken of surface oil slicks from vessels and from the Baffin Queen raft.

3.3 Sampling Strategy

The sampling strategy for the 1981 near-shore spills was similar to the 1980 baseline sampling program. However, an additional bay, Bay 7, was included in the 1981 sampling program as a back-up control bay.

Each experimental bay had two biological transects, a shallow one at 3 m depth and another at 7 m. Each was 150 m long. Much of the hydrocarbon sampling was planned around these reference transects.

Sediment:

The biological transects were sampled every 10 m for sediment. Just off the transects triplicate samples were taken from each of five tissue plots per transect. The sampling strategy consisted of a pre-spill baseline sampling to complement the 1980 baseline sampling program, a second sampling one-two days after the spills, and a third as late as logistics and weather would permit, which was three-four weeks after the spill.

Floc:

Sediment floc was sampled at five locations along (just off) each of the biological transects, on the same schedule as the sediment sampling.

Organisms:

The benthic organisms listed in Table 3.1 were collected for hydrocarbon analysis just off the biological transects. Collections varied depending on the populations available to sample. The sampling schedule was the same as for sediment sampling.

Water:

Water sampling followed a more complex schedule than the pre- and two post- spill samplings. Validation water samples were collected intensively at the time of the spills to provide a check on the flow-through fluorometry system. Similarly, high molecular weight and volatile hydrocarbon samples were taken

mainly in an intensive sampling program immediately after each of the spills. Large volume water samples, on the other hand, were taken at the rate of one per day from the various bays on a rotating basis.

Sediment Traps:

Sediment traps were set out for several days in each bay prior to the spills, then again during each spill, and at intervals thereafter.

4. PRELIMINARY EXPERIMENTS

4.1 Southern Dye Test

In order to test the diffuser system and the oil monitoring equipment prior to shipment north, a southern field trial was conducted on 11 June, 1981, at Cordova Spit, a sand spit near Victoria, B.C. Rhodamine dye mixed with fresh water was used to simulate the oil/seawater dispersion. Four litres of dye were added to fresh water in a swimming pool reservoir, then pumped out over a fifty minute period. Drogues tracked the surface currents, and were positioned by an R.P.S. positioning system to determine surface current velocities. Three flow-through fluorometers monitored the concentrations of the dye in the embayment: two at bottom locations and one providing vertical profiles. A Petrotrack towed underwater fluorometer provided horizontal transects.

The pump and diffuser system were judged to work well, and the system of monitoring the dye cloud with drogues and fluorometers was also judged a success. With minor modifications the same systems were used in the oil spill experiments at Cape Hatt.

4.2 Northern Dye Tests

Dye Test 1

Prior to the dispersed oil spill, a series of dye tests was conducted to determine the water circulation patterns in Bay 9. The original concept of the dispersed oil spill was that the diffuser pipe would extend across the north end of the bay and that the dispersed oil would then be carried south across the experimental area and away from Bay 10, the control bay. In order to test this hypothesis a dye test was conducted on 16 August, 1981, using the same general layout of equipment as for the planned oil spill. The pumping of Rhodamine dye and sea water through the diffuser pipe began at 1010 and continued for one hour. Weather conditions were those judged necessary for the correct water circulation, with southerly winds and a rising tide.

The result of the dye test was disappointing. Much of the shallow dye was carried by wind-induced currents north into control bay 10. Deeper currents (8-15 m) were much weaker than predicted and wandered vaguely west instead of south. Impact on the bottom pumps at the north end of Bay 9 closest to the diffuser pipe was slight and short. At the Baffin Queen station in the centre of the bay no dye was seen, nor was any recorded at the bottom stations at the south end of the bay. Most of the deeper dye missed Bay 9 and went generally westward, then was drawn back north by the changing tide, causing low level contamination at depth of Bays 10 and 11.

The conclusion from this experiment was that the diffuser did a more effective job of contaminating the control bay - Bay 10 - than the experimental bay. Changes were therefore required to devise a more effective configuration. The options in order of their desirability were:

OPTION 1. Wait for weather/tide combinations that give more definite southerly currents in Bay 9.

OPTION 2. Shift the diffuser to the south end of Bay 9 and use the prevailing northerly currents to spread the oil over the experimental area. Probably shift the control bay to Bay 7.

OPTION 3. Use another bay for the dispersed oil experiment.

Dye Test 2

While waiting for the weather conditions to be right for trying option 1, conditions were good for option 2. In order to test the idea of using the diffuser at the south end of Bay 9 without relocating the diffuser pipe, a mini dye test was tried. At 1600, 18 August, 1981, divers released 6 x 30 mL test tubes of rhodamine dye in a line simulating the diffuser pipe. Winds were 10 - 15 kts from the south with heavy rain. This experiment indicated good coverage of the experimental area could be obtained: contamination was achieved at all bottom stations in Bay 9.

The dye test was considered to be positive indication that a successful experiment could be had by dispersing the oil at the south end of Bay 9, allowing it to sweep across the test area carried by the relatively strong and reliable northerly currents, and relying on the currents to sweep most of the oil past Bays 10 and 11, and north into Eclipse Sound.

Dye Test 3

On the evening of the day of the mini dye test (dye test 2) the weather/tide conditions were ideal for generating southerly currents across the experimental area (option 1): the wind was blowing 10 kts from the south with a moderate chop, and the tide was rising. At 2100 all fluorometer stations and the diffuser system were ready for a full scale dye test from the north end of the bay, but the required southerly currents never developed. At 2200 the dye test was aborted. The conclusion was that it was not reasonable to rely on southerly currents in Bay 9, and that option 1 would have to be abandoned. In light of the encouraging results from the mini dye test, the decision was made to move the diffuser system to the south end of Bay 9, and to try a full-scale dye test with that configuration (option 2).

Dye Test 4

The full scale dye test with the diffuser at the south end of Bay 9 began at 1030, 25 August, 1981. The wind was from the north at 10-20 kts, and the tide was beginning to fall from a small high. Dye was pumped out of the diffuser for one hour.

Partly because of the effect of the wind, and partly because of the gyre induced by the topography, the dye in the surface layers (0-10 m) went the wrong direction - south towards Bay 7 - while the deeper dye (10-15 m) went north with the tide-induced current. Some of the surface dye (0-1 m?) blew around the point at the south end of Bay 9 and headed for Bay 7. The remainder of the surface dye circled back into the gyre, and eventually reached the experimental area of Bay 9 an hour or so after being released. Eventually all of the bottom monitoring stations detected high levels of the dye cloud, and at 1700, five hours after pumping had stopped, concentrations were still high. Some dye was also detectable in Bay 10, particularly at depth.

The response to this dye test was that, although the approach of using the gyre was unconventional, it was successful in giving an even contamination of the experimental area. The concern was primarily that the dispersed oil would leak into the other bays. The problem of the wind-blown surface layer, which carried some dye towards Bay 7, the back-up control bay, was a problem that could be solved by closing off the shallowest orifices on the diffuser pipe. The contamination of Bay 10 seemed, however, an insurmountable problem. The decision was made to turn Bay 10 into a second, lower-dose, experimental bay, and to make Bay 7 the control bay.

5. FIELD INSTRUMENT CALIBRATION AND VALIDATION

5.1 Calibration of Flow-through Fluorometers

Fluorometers show a remarkably linear response to rhodamine dye over several orders of magnitude, but unfortunately the same cannot be said of their response to oil. Quenching effects with oil are severe, and variable depending on the oil. The primary reason for the quenching is the very complex mixture of organic compounds which is present in oil, some of which fluoresce, and some of which absorb. There is a strong tendency for charge transfer quenching to occur with an oil sample, and other forms of quenching can also be a problem, such as the micelle effect.

The calibration curves for the fluorometers at the sensitivity settings used for the dispersed oil spill are shown in Figure 5.1. (The Petrotrack broke down immediately prior to the spill, and its sensitivity had to be turned down to reduce noise in the signal to manageable levels. The result is that its calibration curve is different from the other instruments, and its sensitivity is low, see Figure 5.2.) These curves are based on a calibration exercise done immediately after the dispersed oil spill. A photograph of the calibration set-up is shown in Figure 5.3.

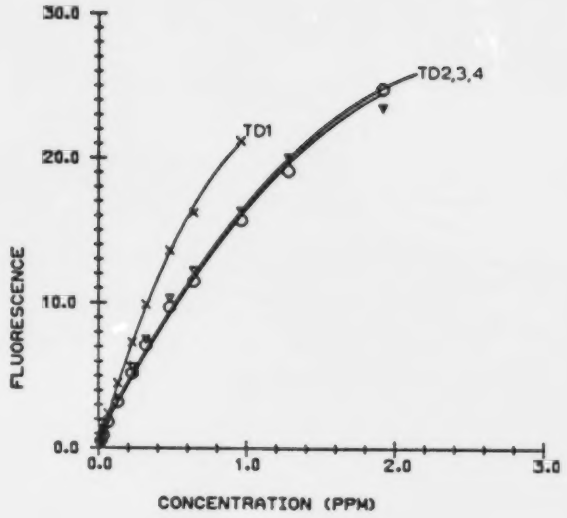
Under the sensitivity adjustment used for the dispersed oil spill, the instruments show a detection limit of about 10 ppb and a reasonably linear response to 1 ppm for the Lagomedio crude and dispersant. Thereafter the quenching effects become more pronounced. Above 15 ppm the quenching is very severe, and above about 50 ppm the instrument response is so nearly flat that it is no longer viable as a detection method. The useful range of the flow-through fluorometer instrumentation with Lagomedio crude is therefore, 0.01 - 50 ppm, or 3 1/2 orders of magnitude.

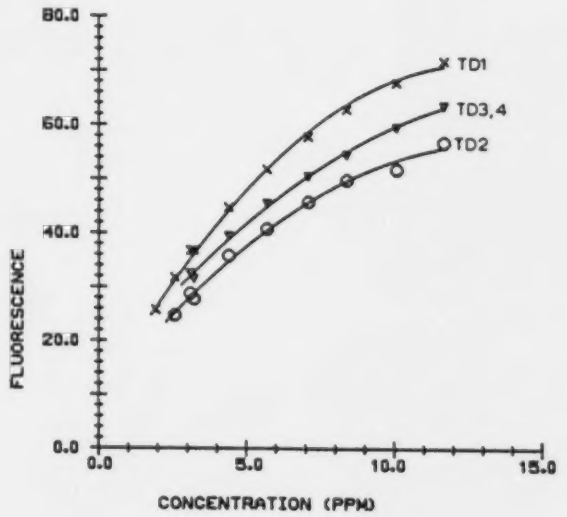
Figure 5.1 Calibration Curves for the Fluorometers over Three Concentration Ranges.

Note:

1. The four Turner Designs fluorometers are identified as TD1 to TD4.

2. Concentrations are as made up in the calibration tanks.





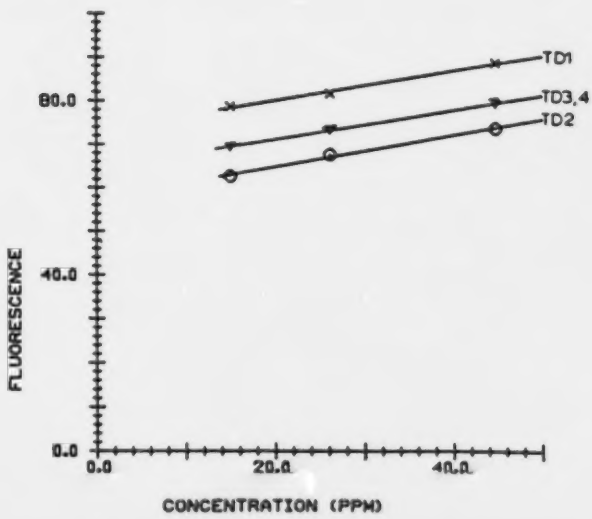


Figure 5.2 Calibration Curve for the Petrotrac Towed Underwater Fluorometer.

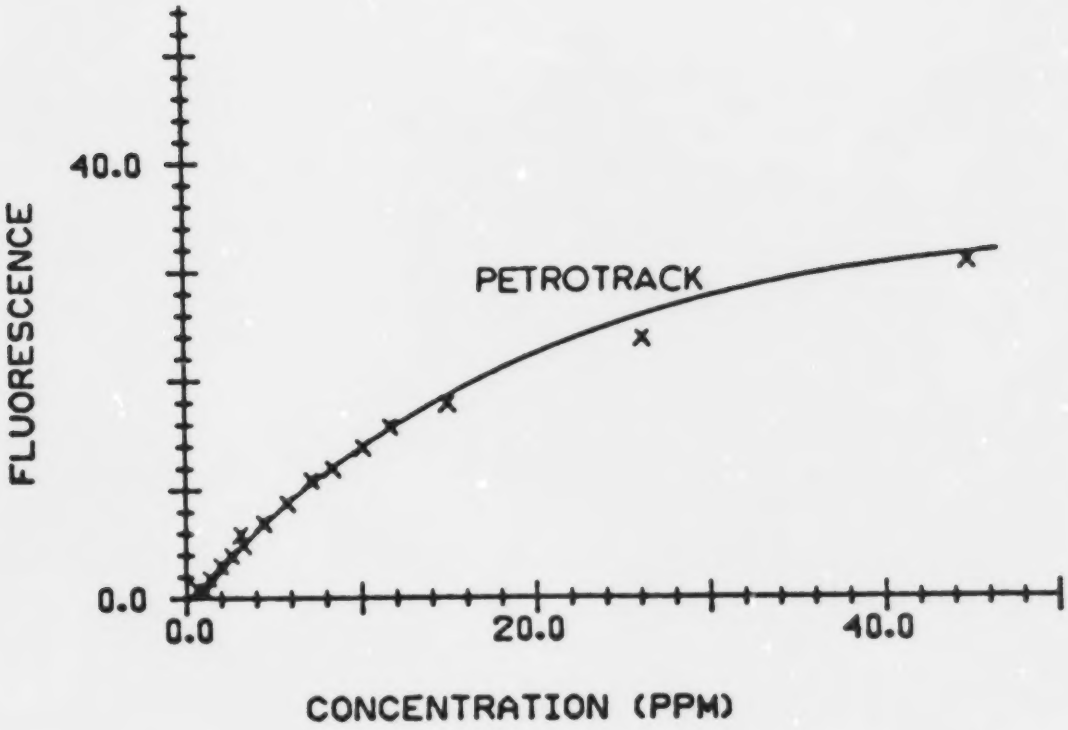
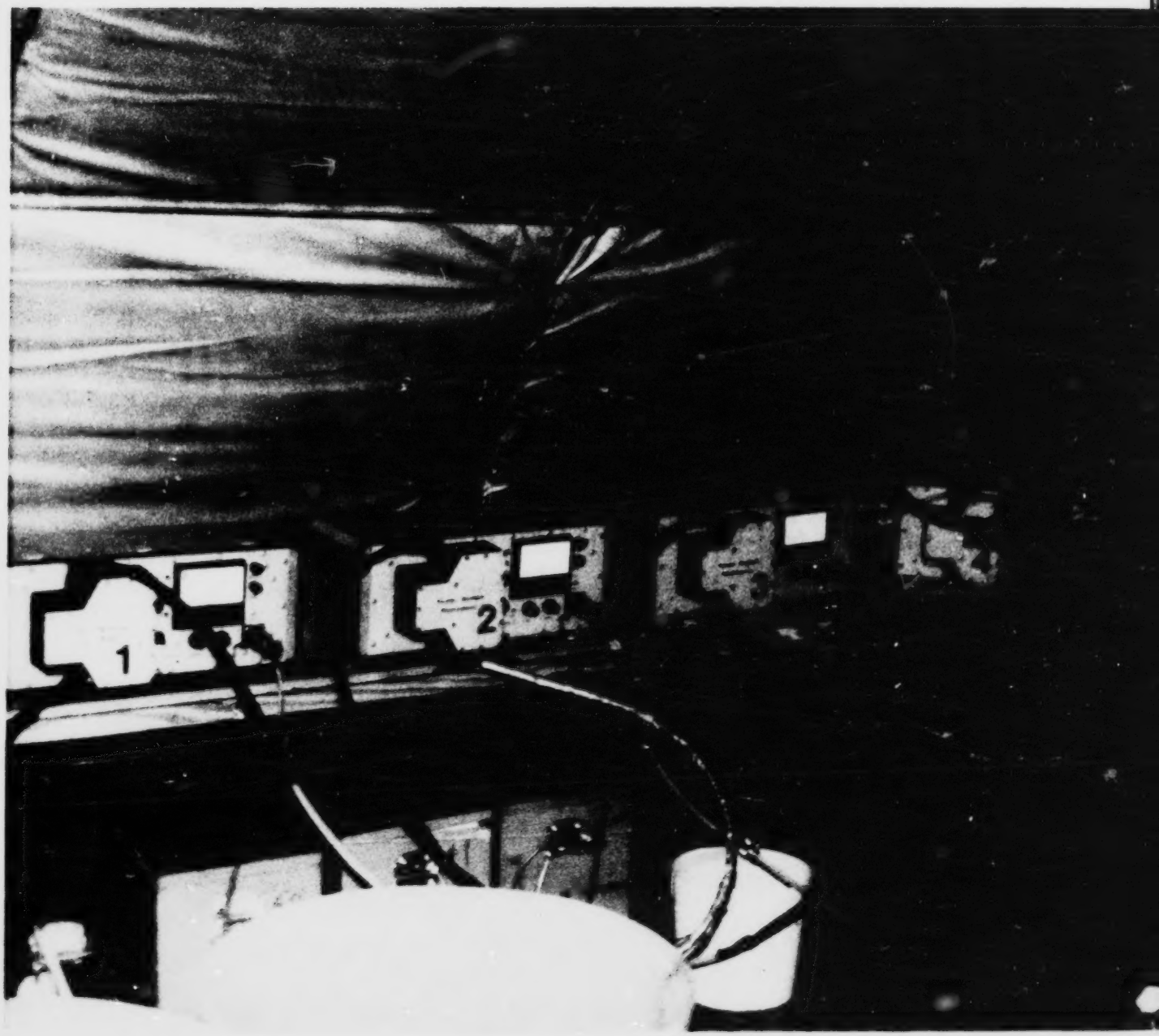


Figure 5.3 Photograph of Calibration of Fluorometers at Cape Hatt.



5.2 Validation of Flow-through Fluorometers

In order to verify the field measurements of oil concentration, 98 one-liter 'validation' samples were taken for laboratory analysis. These validation samples were analyzed by both fluorescence and infra-red techniques and the values obtained were compared with the fluorometer readings obtained in the field (see Table 5.1).

The results of the comparison between the laboratory fluorescence analyses and the field measurements are shown in Figure 5.4. The correlation coefficient between the two methods is 0.946, which is as good as between the two different laboratory methods of analyzing the same sample (correlation coefficient of 0.944). In making this comparison, all pairs in which one or other of the measurements exceeded 55 ppm have been omitted as being above the reliable range of the field fluorescence. (Above about 100 ppm the quenching effect becomes so severe that fluorescence decreases with increasing oil concentration. Therefore, for samples 30 and 31 taken immediately adjacent to the diffuser pipe, it was possible to get 10 ppm indicated by the field fluorescence when the lab determination was 150-200 ppm.)

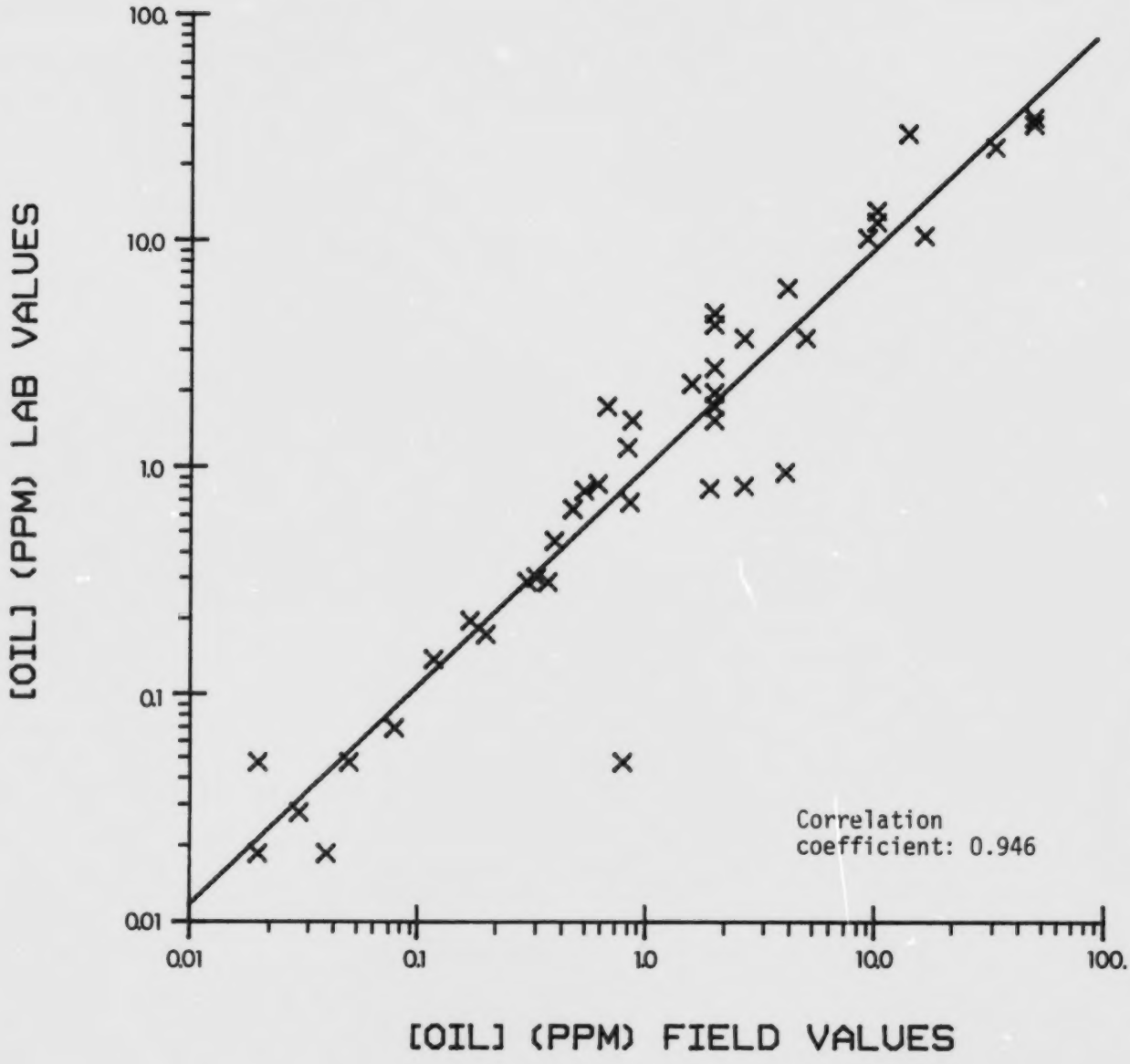


Figure 5.4 Comparison of Field and Laboratory Fluorescence Measurements of Oil Concentrations in the Water Column.

TABLE 5.1

Comparison of Laboratory and Field Measurements of Oil Concentration

Bay 9 Dispersed Oil Spill

1) Shore Station 1, Fluorometer 1

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Field	Lab Fluor.	Lab I.R.
44	81-08-27	1409	10	0.30	0.31	0.4
45	81-08-27	1413	7	0.05	0.05	DL
46	81-08-27	1433	7	0.20	0.18	0.3
47	81-08-27	1605	10	4.1	0.94	3.7
48	81-08-27	1909	3	1.6	2.3	2.6
49	81-08-27	1916	10	2.0	1.6	2.0
54	81-08-27	1612	7	2.0	1.8	5.1
55	81-08-27	1627	10	4.2	6.0	5.6
56	81-08-27	2217	7	34	25.2	24.3
57	81-08-27	2330	3	16.5	10.3	11.7
97	81-08-30	1640	3	0.03	0.01	DL
98	81-08-30	1632	10	0.04	0.01	DL
99	81-08-30	1634	7	0.04	0.02	DL

2) Shore Station 2, Fluorometer 2

68	81-08-27	1406	10	76	23.9	21.0
69	81-08-27	1442	3	0.12	0.14	DL
70	81-08-27	1558	3	1.9	0.79	1
71	81-08-27	1603	10	86	167	122
72	81-08-27	1705	3	2.7	0.82	3.2
73	81-08-27	1715	10	111	91	66
74	81-08-27	1800	10	95	93	66

2) Shore Station 2, Fluorometer 2 (continued)

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Field	Lab Fluor.	Lab I.R.
75	81-08-27	1808	3	9.3	10	8.9
76	81-08-27	1835	10	58	45	37
77	81-08-27	2145	10	5.0	3.6	4.5
81	81-08-28	1642	3	0.08	0.07	DL
95	81-08-30	1655	3	0.00	0.01	DL
96	81-08-30	1647	10	0.02	0.01	DL

3) Baffin Queen, Fluorometer 3

58	81-08-27	1600	0	2.0	2.7	3.0
59	81-08-27	1600	0	2.0	2.1	2.4
60	81-08-27	1600	2	2.0	4.7	2.7
61	81-08-27	1600	2	2.0	4.2	4.2
62	81-08-27	1600	4	10.2	11.8	9.6
63	81-08-27	1600	4	10.2	13.1	10.7
64	81-08-27	1600	6	50	33.5	19.0
65	81-08-27	1600	6	50	31.4	22.8
66	81-08-27	2355	2	0.8	0.05	DL
67	81-08-27	2355	4	0.05	0.01	DL
78	81-08-29	1248	0	0.00	0.02	DL
79	81-08-29	1240	6	0.00	0.02	DL

4) Profile Boat, Fluorometer 4

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Field	Lab Fluor.	Lab I.R.
23	81-08-27	1432	1	0.17	0.21	DL
24	81-08-27	1434	4	2.7	3.6	4.6
25	81-08-27	1436	10	0.00	0.01	DL
26	81-08-27	1651	4	50	88	70
27	81-08-27	1651	4	50	65	54
28	81-08-27	1653	1	14	52	42
29	81-08-27	1653	1	14	29	23
30	81-08-27	1717	10	10.2	192	149
31	81-08-27	1717	10	10.2	237	170
32	81-08-27	1930	15	0.01	0.04	DL
33	81-08-27	1936	10	0.48	0.64	0.8
34	81-08-27	1952	2	0.48	0.64	0.8
35	81-08-27	2005	10	0.37	0.31	0.4
36	81-08-27	2010	4	0.40	0.47	0.6
37	81-08-27	2017	1	0.33	0.32	0.5
38	81-08-28	1040	8.5	0.61	0.84	1.5
39	81-08-28	1138	9	0.86	0.69	3.6
40	81-08-28	1213	8	0.54	0.77	0.8
41	81-08-28	1218	8	0.83	1.2	2.4
42	81-08-28	1338	6.5	0.68	1.8	1.7
43	81-08-28	1304	6	0.87	1.6	3.9
82	81-08-30	1238	11	0.02	0.05	DL
83	81-08-30	1248	2	DL	0.01	DL
84	81-08-30	1245	6	DL	0.07	-
85	81-08-30	1500	8	0.02	0.02	DL
86	81-08-30	1350	10	DL	0.02	DL
87	81-08-30	1355	2	DL	0.01	DL
88	81-08-30	1355	2	0.01	0.02	DL
89	81-08-30	1555	12	DL	0.01	DL
90	81-08-30	1705	0.2	0.03	0.03	DL

4) Profile Boat, Fluorometer 4 (continued)

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Field	Lab Fluor.	Lab I.R.
91	81-08-30	1630	7	0.05	0.05	DL
92	81-08-30	1720	8	0.03	0.03	DL
93	81-08-30	1600	2	0.01	0.01	DL
94	81-08-29	1800	8	DL	DL	DL

5) Samples Collected by Divers

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Lab Analysis Fluor.	Lab Analysis I.R.
50	81-08-27	1755	3	4.2	4.9
51	81-08-27	1755	3	3.1	4.2
52	81-08-27	1755	3	2.3	3.4
53	81-08-27	1755	7	0.9	2.5

Bay 11, Surface Oil Spill. Calibration sample oil concentrations

1) Shore Station 1, Fluorometer 1

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Field	Lab Fluor.	Lab I.R.
07	81-08-20	0950	3	0.54	0.17	DL
08	81-08-20	1030	3	0.60	0.13	DL
09	81-08-20	1135	3	0.17	0.04	DL
10	81-08-20	1230	3	0.01	0.01	DL
11	81-08-20	1420	3	0.02	0.01	DL
12	81-08-20	1628	3	0.02	0.01	DL

2) Shore Station 2, Fluorometer 2

13	81-08-20	1034	7	0.00	0.01	DL
14	81-08-20	1046	3	0.35	0.05	DL
15	81-08-20	1145	10	DL	0.00	DL
16	81-08-20	1151	3	0.08	0.02	DL
17	81-08-20	1245	3	DL	0.01	DL

3) Profile Boat, Fluorometer 4

01	81-08-20	1124	0.1	2.77	1.22	DL
02	81-08-20	1236	0.5	1.35	0.80	DL
03	81-08-20	1537	0.1	1.35	0.09	DL
04	81-08-20	1546	3	0.00	0.02	DL
05	81-08-20	1635	0.2	0.52	0.14	DL
06	81-08-20	1700	0.5	0.88	0.23	DL

4) Samples Collected by Hand

I.D.	DATE	TIME	DEPTH (m)	OIL CONCENTRATION (ppm) Lab Analysis Fluor.	I.R.
18	81-08-23	-	0.02-0.1	0.92	DL
19	81-08-22	1600	0.02-0.1	0.30	DL
20	81-08-21	1600	0.02-0.1	38	30
21	81-08-22	1600	0.02-0.1	7.5	5.1
22	81-08-22	-	0.02-0.1	7.8	3.0

Note:

1. DL = below detection limit. For the laboratory analyses, the infrared method detection limit was 0.3 ppm and the fluorescence method detection limit was 0.01 ppm. The field fluorescence detection limit was 0.01 ppm.

6. RESULTS: Surface Oil Spill

The surface oil spill began at 1540 on 19 August, 1981. Slightly aged Lagomedio crude oil was pumped from a spill plate over a six-hour period, moving on to and along the beach of Bay 11 under the influence of a north-westerly breeze and a slight alongshore current. Wave action was very slight. (See photograph, Figure 6.1).

The spill resulted in oil coating the beach over its intertidal area as the tide fell. On the rising of the tide, some of the oil lifted off the beach and was collected by the Coast Guard clean-up crew. The total oil spill was 75 drums, of which an estimated 37 drums were collected in the day or so following the spill.

In order to determine the impact of the oil spill on the benthos we deployed two shore stations, each monitoring three bottom pumps. The pumps were placed at approximate depths of 1, 3 and 5 m at the locations shown in Figure 6.2 and were monitored for 36 hours. In addition, a third fluorometer was placed on a vessel and provided vertical profile information.

The results of the flow-through fluorometer monitoring are presented in the time series and profile graphs which follow. The instruments show that oil is only in the surface water to a depth of one meter or so. The monitoring pumps at 3 and 5 m never detected oil during the 36-hour monitoring period, and the 1 m pump detected oil only at low tide. The profiles document repeatedly that the oil remained in the top meter of the water column throughout the post-spill monitoring period. The exposures which would be expected for the two biological transects, which were at 3 and 7 m, would therefore be below the detection limit of 0.25 ppm-h over the 36-hour monitoring period.

Figure 6.1 Photograph of the Surface Oil Spill, Bay 11, Cape Hatt, 19 August 1981.

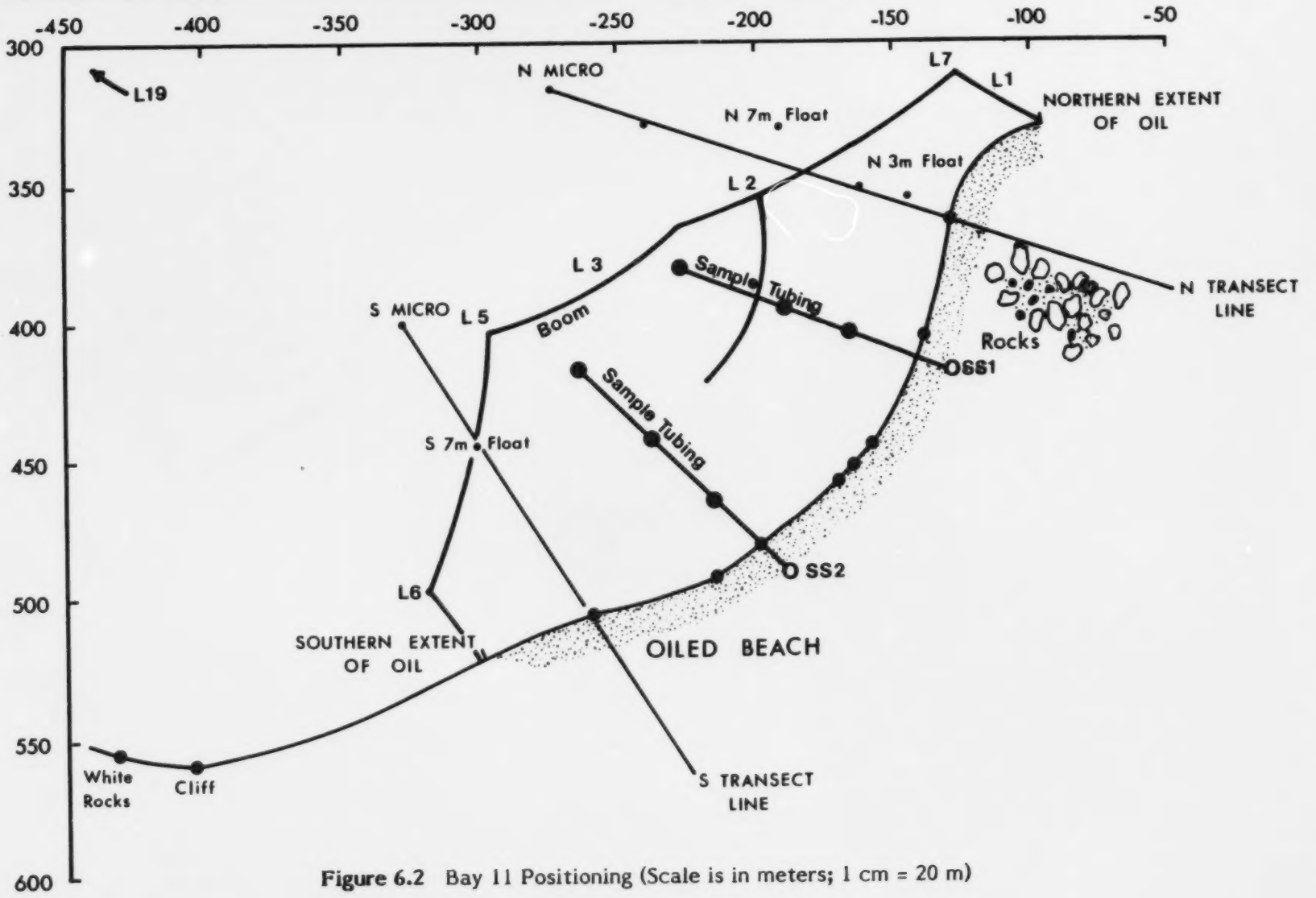


Figure 6.2 Bay 11 Positioning (Scale is in meters; 1 cm = 20 m)

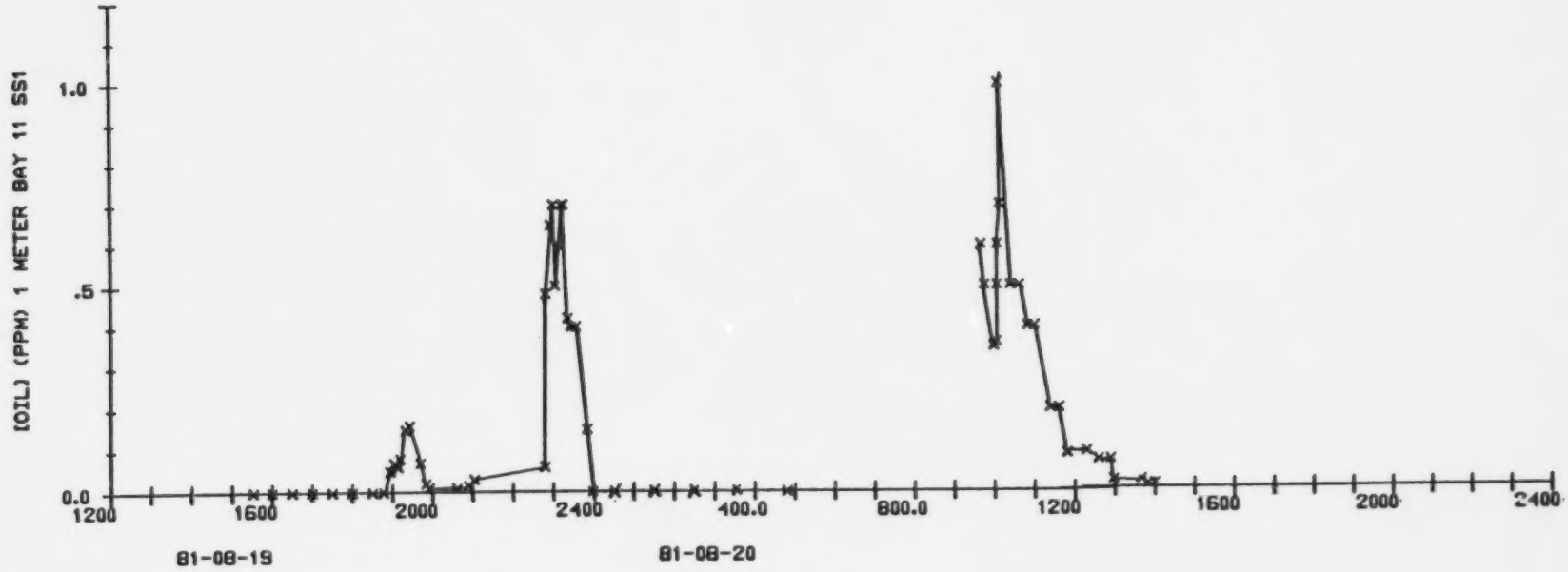


Figure 6.3 Time Series from Bay 11, Shore Station 1, 1 m depth. (Pumps at 3 and 5 m showed no response over the monitoring period.)

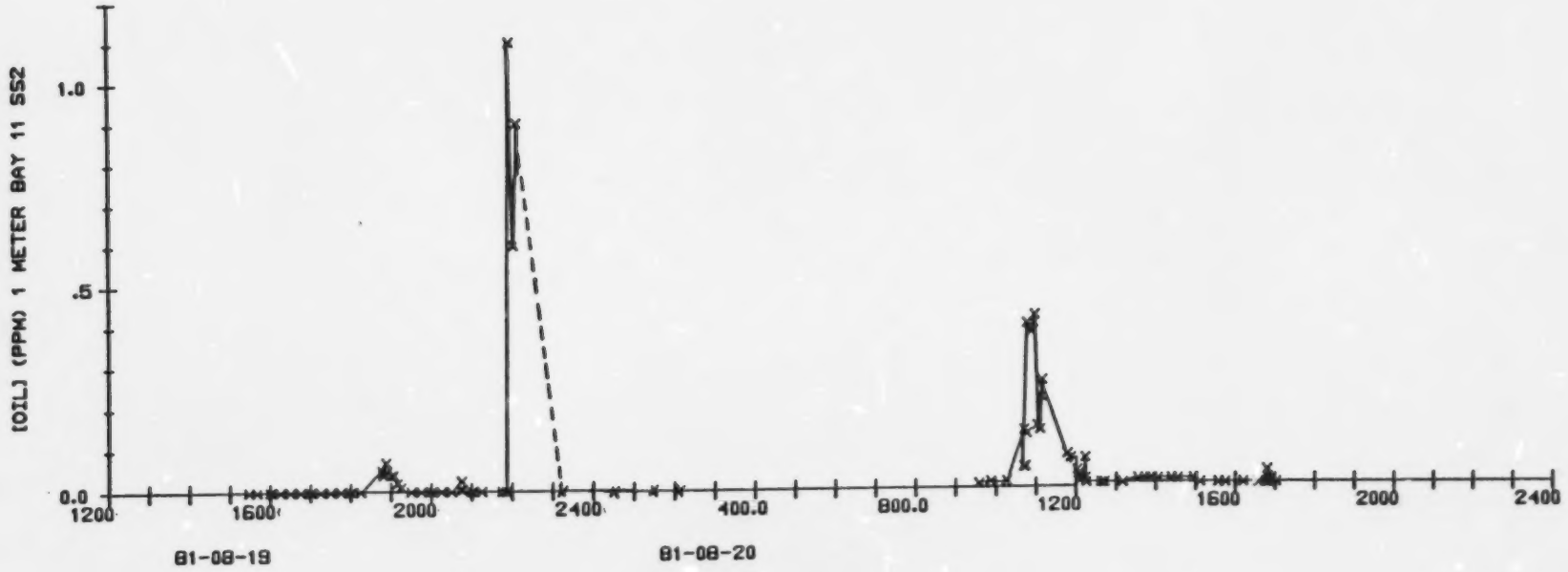


Figure 6.4 Time Series from Bay 11, Shore Station 2, 1 m (Pumps at 3 and 5 m showed no response over the monitoring period.)

TABLE 6.1

SURFACE OIL SPILL
PROFILE DATA FILES

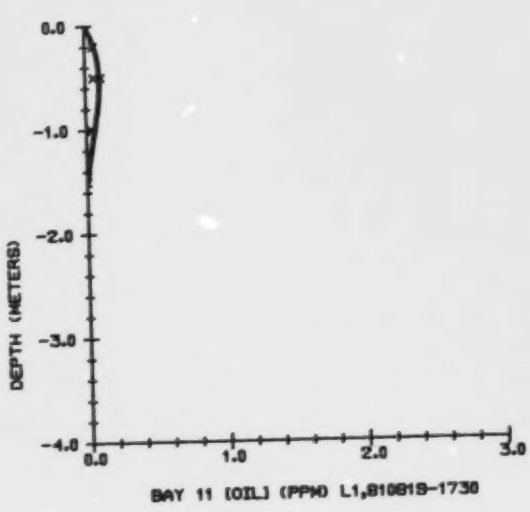
I.D.	LOCATION (refer to Figure 6.2)	DATE 81-08-	TIME EDT	MAX. CONC. (ppm)	DEPTH OF MAX. CONC. (m)
101	1	19	1611	0.04	0.1
102	1	19	1617	0	
103	6	19	1625	0	
104	6	19	1655	0.06	0.5
105	6	19	1708	0.02	0.5
106	1	19	1730	0.11	0.5
107	1	19	1755	0.33	0.25
108	6	19	1811	0.02	0.5
109	1	19	1833	0.16	0.25
110	7	19	1900	0.07	0.1
111	7	19	1921	0.08	0.1-0.5
112	5	19	2053	0.22	0.05
113	2	19	2150	1.4	0.15
114	1	20		2.8	0.1
115	5	20	1245	1.5	0.5, 0.6
116	5	20	1515	1.38	0.1
117	4	20	1616	0.4	0.1, 0.2
118	19	20	1650	0.54	0.5

Figure 6.5 Profiles of Oil Concentrations in Bay 11 after the Surface Oil Spill.

Profiles are in chronological order. The caption for each profile indicates:

Bay, location (L1 etc.), date (year, month, day), time.

Locations are shown on the map, Figure 6.2.



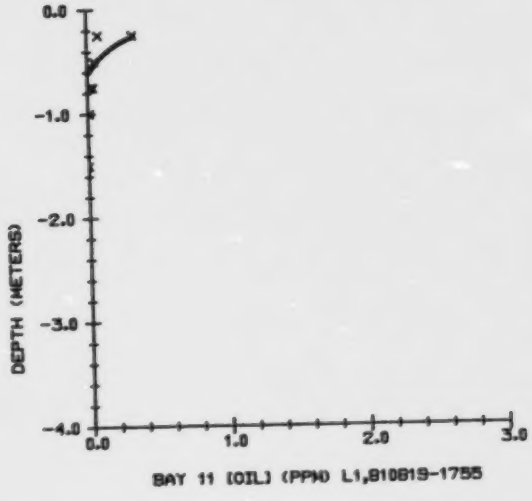
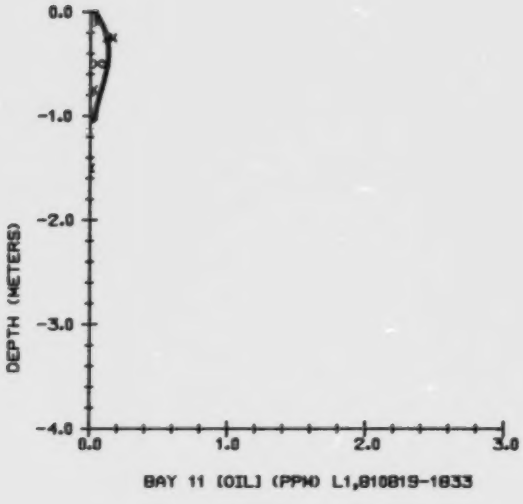
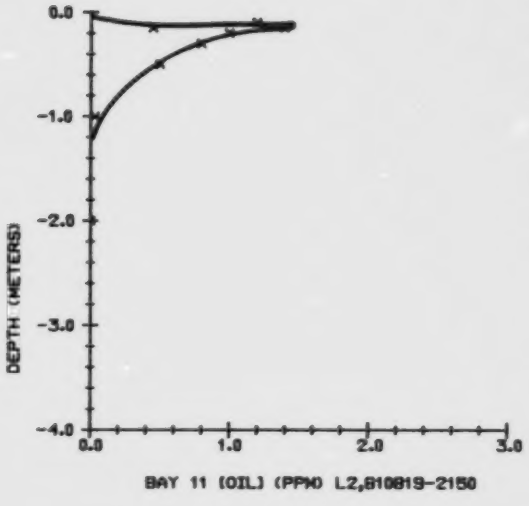


Figure 6.5 (continued) Profiles, Bay 11, 19 August, 1982.





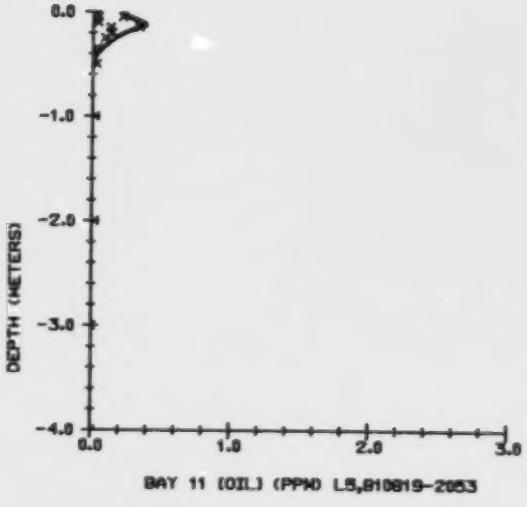
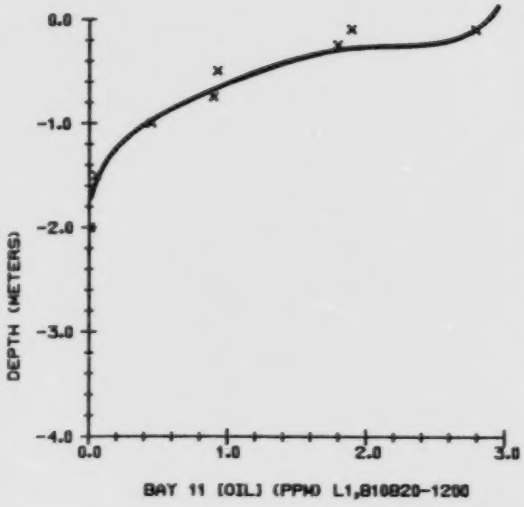
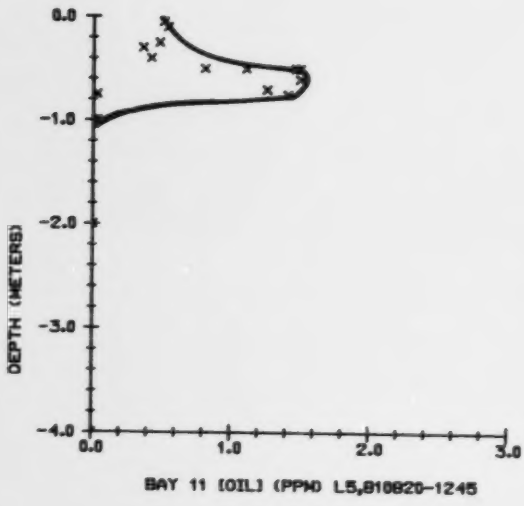
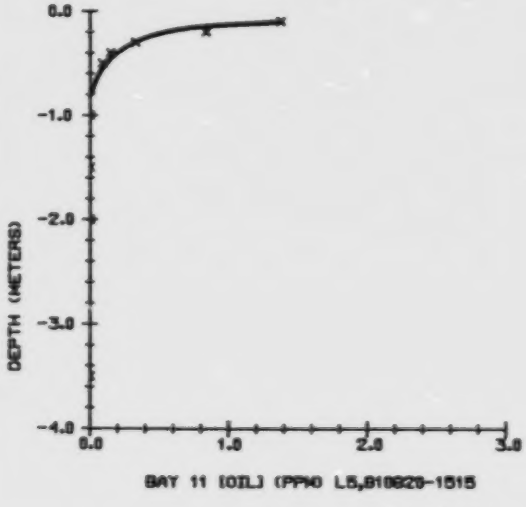


Figure 6.5 (continued) Profiles, Bay 11, 20 August, 1982.







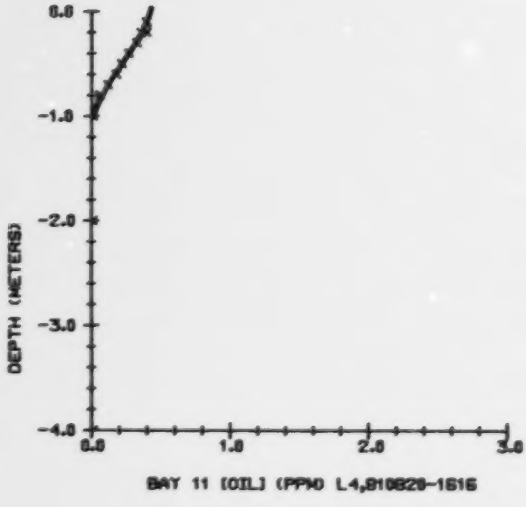


TABLE 6.2

TOTAL HYDROCARBONS IN BEACH SEDIMENT, BAY 11

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
	Bay 11 Prespill 1	81-08-19	0
	2		0
	3		trace
	4		0
	5		trace
	6		0
	Bay 11 Spill Tr 4 Hi	81-08-19	36,000
	Bay 11 Spill Tr 4 Mid	81-08-19	31,000
	Bay 11 Spill Tr 4 Low	81-08-19	6,870
	Bay 11 Spill Tr 6 Hi	81-08-19	20,000
	Bay 11 Spill Tr 6 Mid	81-08-19	7,560
	Bay 11 Spill Tr 6 Low	81-08-19	2,830
	Bay 11 Spill Tr 2A Surface	81-08-20	7,050
	Bay 11 Spill Tr 2A Subsurface	81-08-20	90
	Bay 11 Spill Tr 2B Surface	81-08-20	480
	Bay 11 Spill Tr 2B Subsurface	81-08-20	50
	Bay 11 Spill Tr 2C Surface	81-08-20	18,000
	Bay 11 Spill Tr 2C Subsurface	81-08-20	60
	Bay 11 Spill Tr 4A Surface	81-08-20	3,440
	Bay 11 Spill Tr 4A Subsurface	81-08-20	140
	Bay 11 Spill Tr 4B Surface	81-08-20	4,800
	Bay 11 Spill Tr 4B Subsurface	81-08-20	60
	Bay 11 Spill Tr 4C Surface	81-08-20	470
	Bay 11 Spill Tr 4C Subsurface	81-08-20	200
	Bay 11 Spill Tr 6A Surface	81-08-20	16,000

TABLE 6.2 (continued)

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
	Bay 11 Spill Tr 6A Subsurface	81-08-20	560
	Bay 11 Spill Tr 6B Surface	81-08-20	6,090
	Bay 11 Spill Tr 6B Subsurface	81-08-20	170
	Bay 11 Spill Tr 6C Surface	81-08-20	7,340
	Bay 11 Spill Tr 6C Subsurface	81-08-20	180
1000	Bay 11 Tr 1 Upper Surface	81-08-28	2,840
1001	Bay 11 Tr 1 Upper Subsurface	81-08-28	220
1002	Bay 11 Tr 1 Mid Surface	81-08-28	6,400
1003	Bay 11 Tr 1 Mid Subsurface	81-08-28	320
1004	Bay 11 Tr 1 Lower Surface	81-08-28	4,540
1005	Bay 11 Tr 1 Lower Subsurface	81-08-28	190
1006	Bay 11 Tr 3 Upper Surface	81-08-28	190
1007	Bay 11 Tr 3 Upper Subsurface	81-08-28	140
1008	Bay 11 Tr 3 Mid Surface	81-08-28	11,000
1009	Bay 11 Tr 3 Mid Subsurface	81-08-28	110
1010	Bay 11 Tr 3 Low Surface	81-08-28	2,050
1011	Bay 11 Tr 3 Low Subsurface	81-08-28	380
1012	Bay 11 Tr 6 Upper Surface	81-08-28	18,000
1013	Bay 11 Tr 6 Upper Subsurface	81-08-28	5,800
1014	Bay 11 Tr 6 Mid Surface	81-08-28	6,540
1015	Bay 11 Tr 6 Mid Subsurface	81-08-28	450
1016	Bay 11 Tr 6 Low Surface	81-08-28	8,270
1017	Bay 11 Tr 1 Low Subsurface	81-08-28	500
1121	Bay 11 Tr 1 Upper Surface	81-09-15	3,920

TABLE 6.2 (continued)

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
1122	Bay 11 Tr 1 Upper Subsurface	81-09-15	trace
1123	Bay 11 Tr 1 Mid Surface	81-09-15	1,920
1124	Bay 11 Tr 1 Mid Subsurface	81-09-15	330
1125	Bay 11 Tr 1 Low Surface	81-09-15	1,860
1126	Bay 11 Tr 1 Low Subsurface	81-09-15	240
1127	Bay 11 Tr 3 Upper Surface	81-09-15	260
1128	Bay 11 Tr 3 Upper Subsurface	81-09-15	trace
1129	Bay 11 Tr 3 Mid Surface	81-09-15	12,000
1130	Bay 11 Tr 3 Mid Subsurface	81-09-15	240
1131	Bay 11 Tr 3 Low Surface	81-09-15	5,820
1132	Bay 11 Tr 3 Low Subsurface	81-09-15	trace
1133	Bay 11 Tr 6 Upper Surface	81-09-15	17,000
1134	Bay 11 Tr 6 Upper Subsurface	81-09-15	220
1135	Bay 11 Tr 6 Mid Surface	81-09-15	6,500
1136	Bay 11 Tr 6 Mid Subsurface	81-09-15	360
1137	Bay 11 Tr 6 Low Surface	81-09-15	3,640
1138	Bay 11 Tr 6 Low Subsurface	81-09-15	540

Notes:

1. 0 = not detectable. Detection limit is 20 mg/kg.
2. trace = 20 mg/kg < trace < 50 mg/kg.

7. RESULTS: Dispersed Oil Spill

The dispersed oil spill began at 1300 on 27 August, 1981. Seventy-five drums of slightly aged (8% by volume) Lagomedio crude oil were mixed with 10% Corexit 9527 dispersant, then pumped out a diffuser pipe laid along the bottom at the south end of the experimental area as a 5:1 seawater:oil mix. (See Dickins, 1982, for a full discussion of the pump and diffuser system.)

To monitor the dispersed oil spill we deployed five flow-through fluorometers:

1. Two shore stations were set up as for the oil-only spill, each monitoring pumps at approximate depths of 3, 7 and 10 m.
2. In the centre of the bay, the raft 'Baffin Queen' was used to monitor depths of 0, 2, 4 and 6 m via a four-way manifold.
3. A Boston whaler was equipped with a fluorometer and a pump for vertical profiling;
4. A seatruck was used to tow the Petrotrack submersible fluorometer for horizontal profiling.

A photograph of the spill is included as Figure 7.1, and locations of equipment, transects, etc. are shown drawn to scale in Figure 7.2. The time series for each of the continuous monitoring stations are shown in summary in Figure 7.3, and in detail in Appendix A. Vertical profile data are summarized in Table 7.1, and presented in detail in Appendix B. (Petrotrack data are not reported because a failure in the instrument immediately prior to the spill reduced its sensitivity to marginal levels.)

The data documents the movement of two distinct oil clouds. Deep oil (7 - 15 m) moved directly north with the offshore current, while shallow oil circulated around the south end of Bay 9 before reaching the experimental area some six hours later. The oil tended to stay at the depth it was released, but dispersed horizontally rapidly. After four days it had spread throughout Ragged Channel at 30-50 ppb, and some cross contamination of the various bays had occurred.

A check was made of the oil composition about 12 hours after the commencement of pumping to look for evaporative losses which would distort the fluorometer measurements of oil concentration. The comparison of the experimental

oil with oil from the water column at midnight, 27 August, is shown in Figure 7.4. There is very little evaporation evident over this time period. Boehm et al. (1982) confirm the lack of evaporative weathering.

Total hydrocarbon concentrations from a suite of beach samples from Bay 9 are reported in Table 7.2 and indicate very little oil reached the beach.

Figure 7.1 Photograph of Dispersed Oil Spill, Bay 9, Cape Hatt, 27 August 1982.

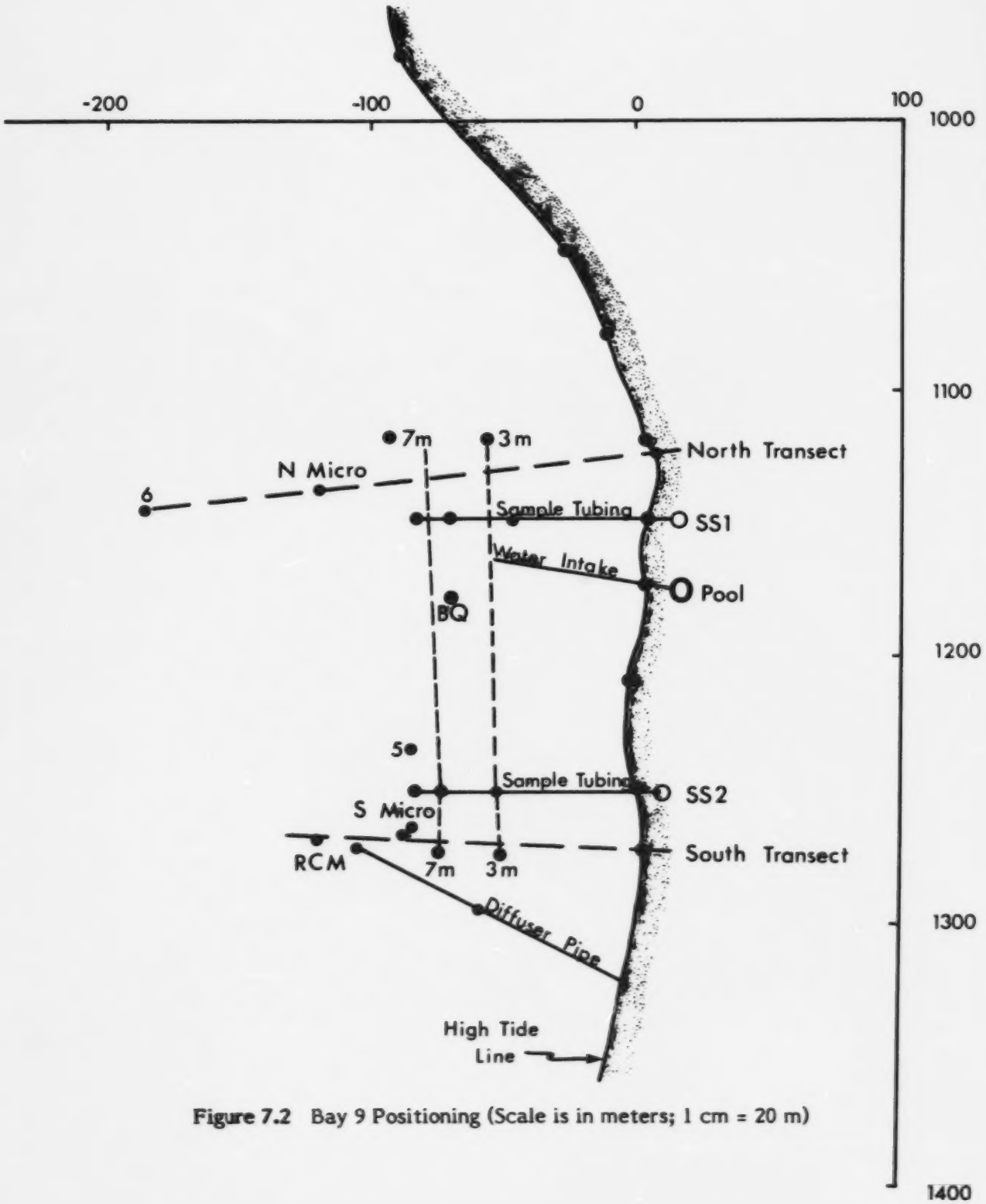
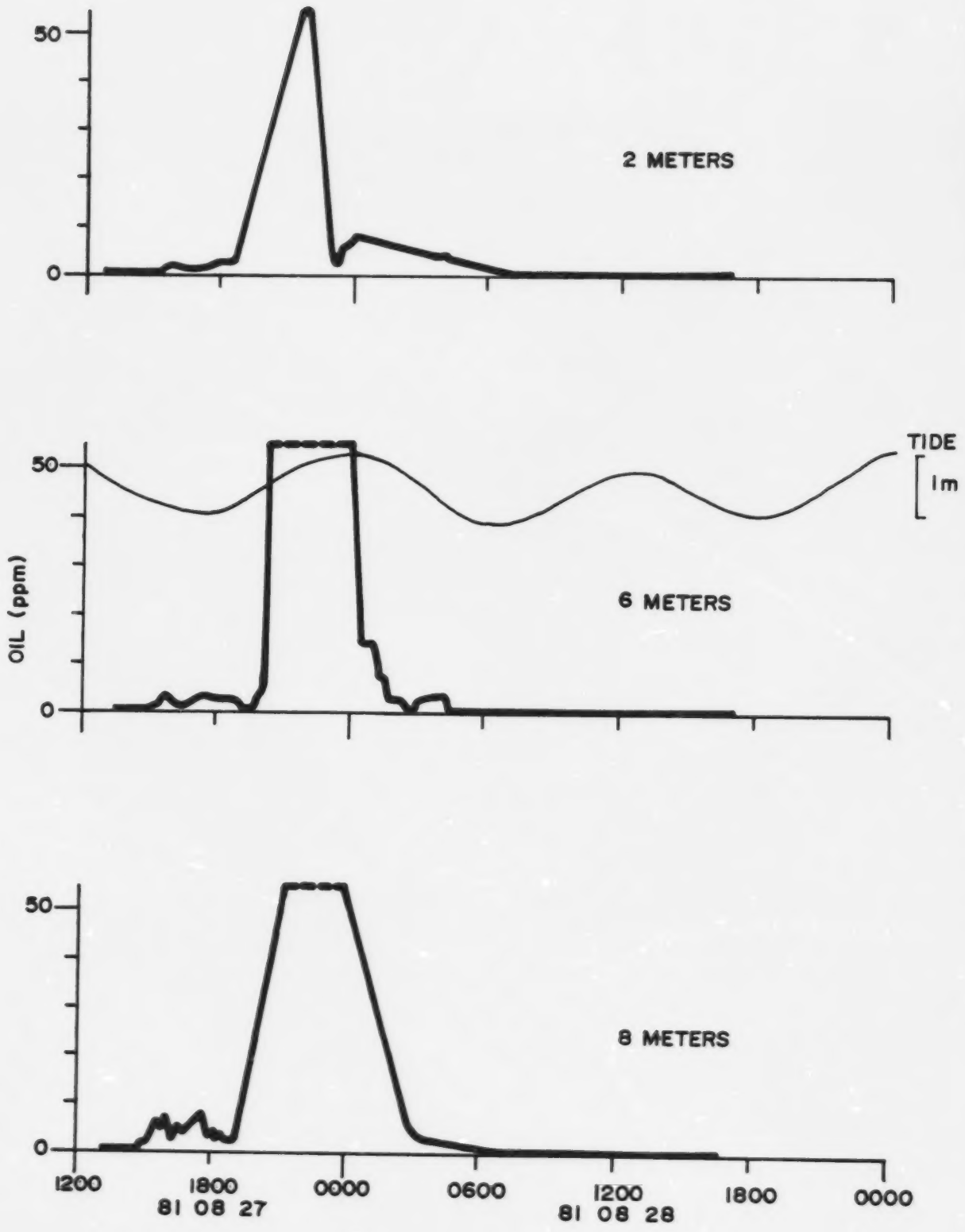


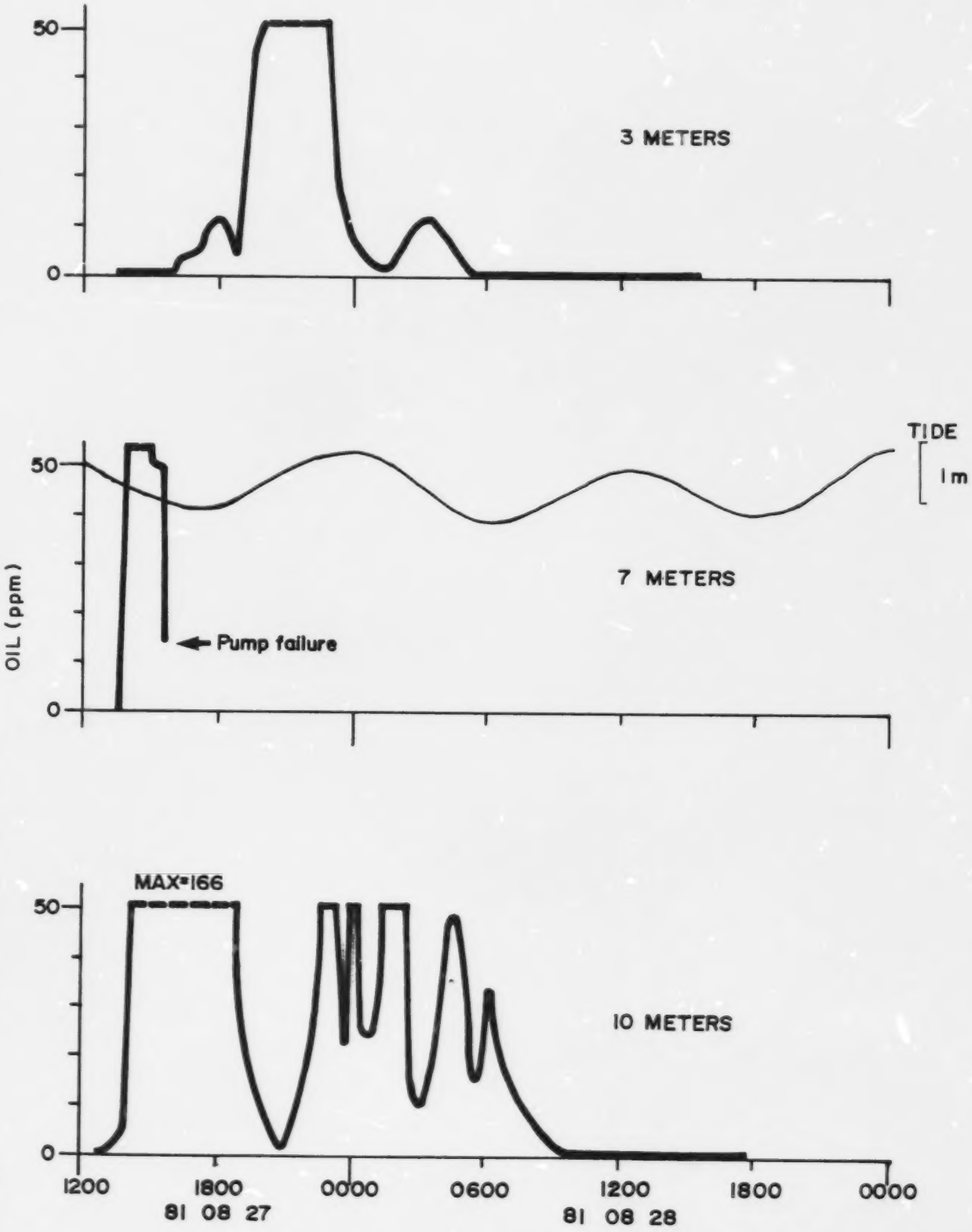
Figure 7.2 Bay 9 Positioning (Scale is in meters; 1 cm = 20 m)

Figure 7.3 Summary Time Series Plots of Oil Concentrations from the Dispersed Oil Spill.

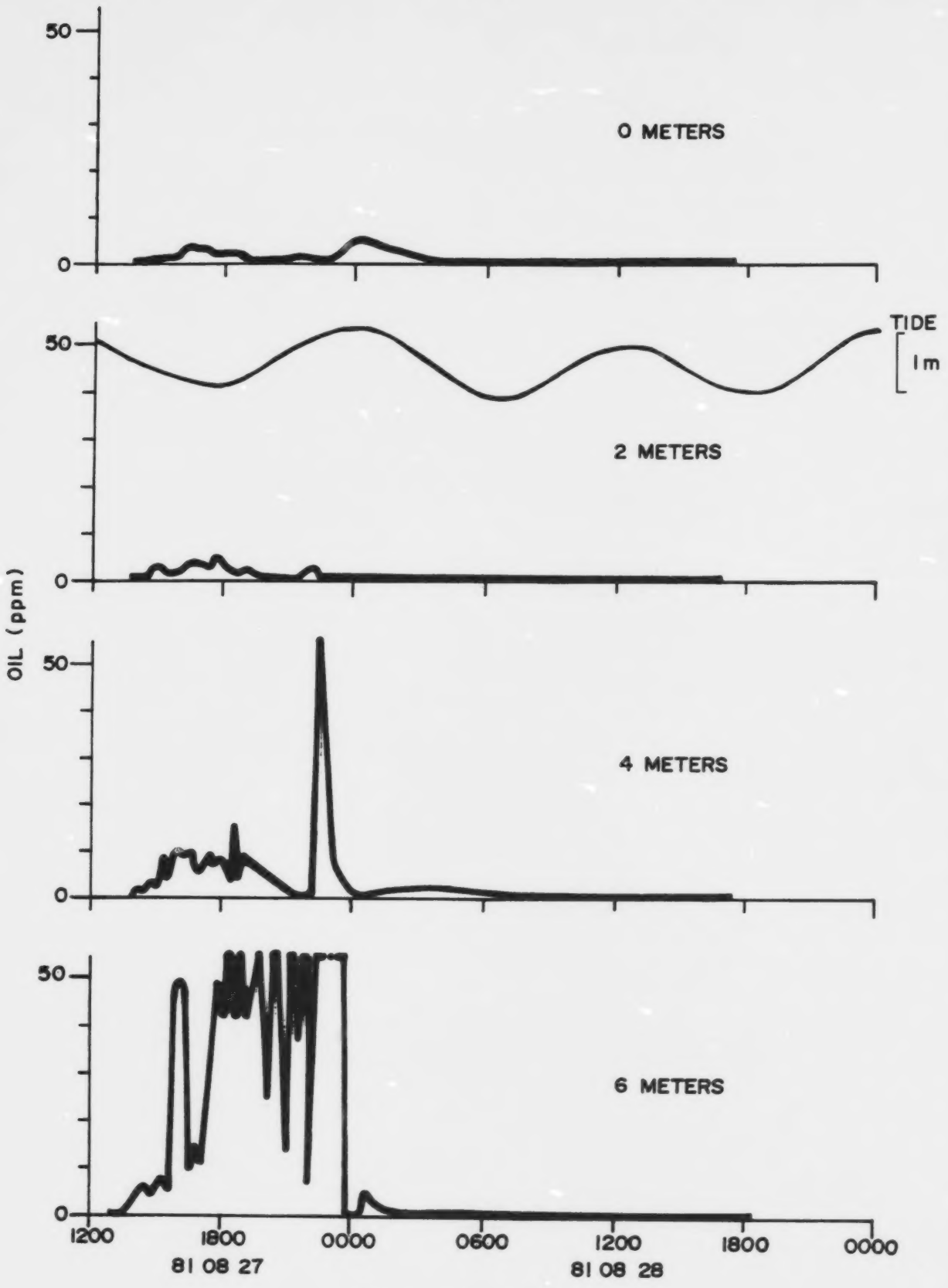
The following three pages summarize the time series data on oil concentrations from Bay 9 from the two shore stations and the Baffin Queen raft. Detailed time series plots showing data points are included as Appendix A.



BAY 9 SHORE STATION 1



BAY 9 SHORE STATION 2



BAY 9 BAFFIN QUEEN

TABLE 7.1

DISPERSED OIL SPILL
PROFILE DATA FILES

I.D.	LOCATION (refer to Figure 6.2)	DATE 81-08-	TIME EDT	MAX. CONC. (ppm)	DEPTH OF MAX. CONC. (m)
01	9 S. Micro	27	1307	0	
02	9 N Micro	27	1333	32	10
03	9 S Micro	27	1345	3.1	10
04	9 N tran. 7 m	27	1350	0.24	6
05	9 S tran. 3 m	27	1400	0.55	3.5
06	9 S Micro	27	1415	3.5	4
07	9 S tran. 7 m	27	1455	6.4	5
08	9 N tran. 7 m	27	1505	2.32	3
09	10 S Micro	27	1530	0.94	6
10	9 S of Dif	27	1548	4.2	0.5
11	9 80 m S of D	27	1554	55	1
12	9 N Micro	27	1613	31	12
13	9 50 m S of D	27	1645	55	4
14	10 N Micro	27	1730	0.43	4
15	10 N tran. 7 m	27	1800	0.39	3
16	10 N tran. 3 m	27	1810	0.42	2.5
17	10 BQ	27	1815	0.35	1-3
18	10 S Micro	27	1830	0.47	10
19	10 S tran. 3 m	27	1850	0.18	0.5
20	10 S tran. 7 m	27	1905	0.34	1
21	10 S Micro	27	1925	0.52	10
22	10 N Micro	27	2000	0.33	4
23	9 S Micro	27	2310	10.5	8
24	9 SS 2-7 m	27	2330	8.9	5
25	9 N Micro	27	2340	27.8	9
26	9 South Rocks	28	0012	4.4	10
27	Bay 7	28	0039	0	

TABLE 7.1 (continued)

DISPERSED OIL SPILL
PROFILE DATA FILES

I.D.	LOCATION (refer to Figure 6.2)	DATE 81-08-	TIME EDT	MAX. CONC. (ppm)	DEPTH OF MAX. CONC. (m)
28	10 S Micro	28	0105	6.6	5
29	10 N Micro	28	0210	5.2	5
30	9 N Micro	28	1020	0.83	10.5
31	9 N Micro	28	1040	1.6	9.5
32	9 SS 2-7 m	28	1120	0.08	4,5
33	9 S Micro	28	1132	2.65	9
34	10 S Micro	28	1201	1.05	5.5
35	10 N Micro	28	1245	0.92	6
36	10 BQ	28	1326	0.85	7
37	10 S Micro	28	1355	1.2	7
38	7 Centre	28	1432	0	
39	11 S Micro	28	1505	0.14	3,4
40	11 N Micro	29	0940	0.05	8
41	11 S Micro	29	0957	0.11	8
42	11 BQ	29	1013	0	
43	10 N Micro	29	1027	0.22	10
44	10 S Micro	29	1100	0.23	10
45	10 BQ	29	1110	0.12	5
46	9 N Micro	29	1120	0.28	5
47	9 BQ	29	1145	0.22	5
48	7	29	1305	0.07	6
49	7	29	1315	0.12	5
50	9 S Micro	29	1334	0.12	5
51	9 S Micro	29	1340	0.11	1
52	-				
53	7	28	2055	0	
54	10 S Micro	28	2120	0.22	6

TABLE 7.1 (continued)

DISPERSED OIL SPILL
PROFILE DATA FILES

I.D.	LOCATION (refer to Figure 6.2)	DATE 81-08-	TIME EDT	MAX. CONC. (ppm)	DEPTH OF MAX. CONC. (m)
55	10 N Micro	28	2130	0.15	6
56	10 BQ	28	2150	0.15	5
57	9 Jet Str.	28	2200	0.32	6
58	7	29	1645	0.08	6
59	7	29	1700	0.08	8
60	7 S tran. 7 m	29	1713	0.05	7
61	7 N tran. 7 m	29	1720	0.04	7
62	7 N tran. 3 m	39	1725	0	
63	7 S tran. 7 m	29	1730	0.05	7
64	7 S tran. 3 m	29	1750	0	
65	Mid Channel	29	1755	0.06	7
66	Mid Channel	29	1820	0.07	8.5
67	West Side Ch.	29	2000	0	
68	11 N Micro	30	1221	0.03	8-11
69	11 N Micro	30	1240	0.04	10,11
70	11 S Micro	30	1250	0.04	4-11
71	11/12	30	1300	0.06	17
72	Mid Rag Ch.	30	1330	0.04	3
73	Mid Rag Ch.	30	1340	0.03	7,15-18
74	10 N Micro	30	1350	0.03	4-12
75	10 S Micro	30	1410	0.05	8-12

TABLE 7.1 (continued)

DISPERSED OIL SPILL
PROFILE DATA FILES

I.D.	LOCATION (refer to Figure 6.2)	DATE 81-08-	TIME EDT	MAX. CONC. (ppm)	DEPTH OF MAX. CONC. (m)
76	9 S Micro	30	1430	0.04	10
77	9 N Micro	30	1445	0.05	13
78	Milne Inlet	30	1540	0	
79	S Ent. Rag Ch.	30	1620	0.04	3,7
80	7	30	1655	0.03	6,8

Note:

Most of these profiles are presented in chronological order in Appendix B.

Figure 7.4 Comparison of Gas Chromatograms of Lagomedio Crude Oil and a Water Extract from Bay 9.

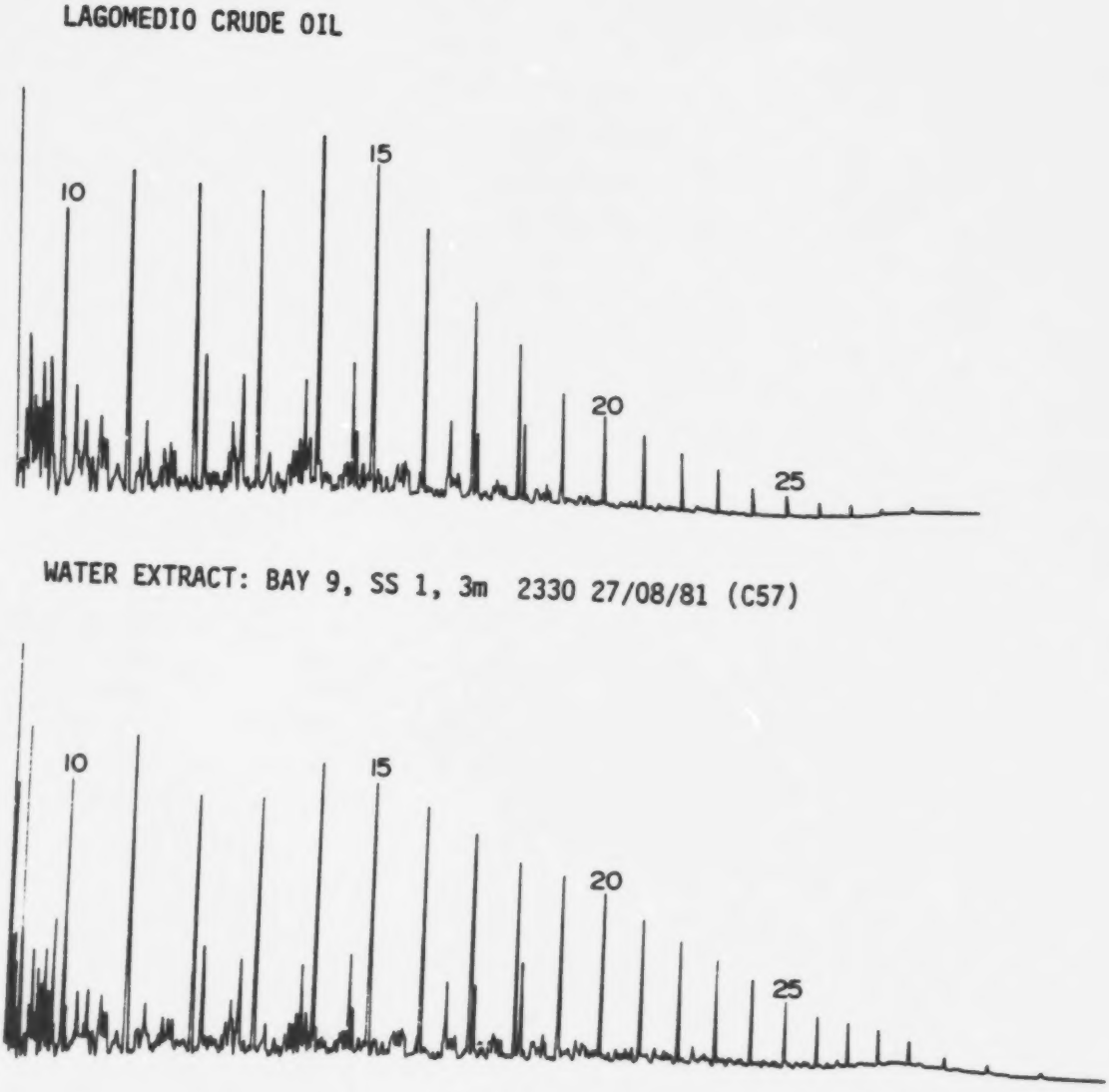


TABLE 7.2

TOTAL HYDROCARBONS IN BEACH SEDIMENT, BAY 9

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
	Bay 9 Profile 100 Upper Surface	81-08-28	1,260
	Bay 9 Profile 100 Mid Surface	81-08-28	0
	Bay 9 Profile 300 Upper Surface	81-08-28	0
	Bay 9 Profile 300 Mid Surface	81-08-28	0
	Bay 9 Profile 600 Upper Surface	81-08-28	0
	Bay 9 Profile 600 Mid Surface	81-08-28	0

Note:

0 = not detectable. Detection limit is 20 mg/kg.

8. RESULTS: Shoreline Spills

A variety of experiments were done along the shoreline of 'Coal Oil Point' in Z lagoon to determine the effectiveness of various countermeasures. Along a 200 m stretch of beach, mixing, gelling agent and dispersants were tried. The sampling method was designed to reduce the sampling-induced variability that was a problem in 1980. Large samples (500-800 g) were taken, and often were composited in sets of four.

The results of these analyses are tabulated in Appendix C and are discussed in detail by Owens et al., 1982.

9. DISCUSSION

9.1 The Surface Oil Spill

The surface oil spill began at 1540, 19 August, 1981. Oil was pumped for six hours from a spill plate at the south end of the beach and moved northwards along the beach under the influence of a slight on-shore breeze and a long-shore current.

The six pumps deployed underneath the oil slick at depths of 1, 3 and 5 m were unable to detect any oil for the duration of the pumping. No response was obtained until about midnight when low tide brought the slick close enough to the 1 m pumps to give a maximum measurement of 1 ppm and an instrument response that lasted about one hour, until the tide rose again. Data from vertical profiles documented that initial penetration of the oil into the water column was very limited, not exceeding 1 m for the first day of the spill. The continuous monitoring pumps did not record any further signal until low tide on 20 August again brought the slick close enough to the 1 m pump. On this, the second day of the spill, the vertical profiles showed that penetration of the oil into the water column was increasing. Oil now extended to a depth of 1.5 m and concentrations were higher, up to 3 ppm.

Calculations of the exposures of the various pump locations to oil (concentration x time exposed) are presented in Table 9.1. Since the 1 m pumps were the only ones to show any instrument response, these were the only ones to have any exposure hours. The biological transects at 3 and 7 m were, therefore, apparently not exposed to measurable oil over the 36 hour period of continuous monitoring. Contamination by oil could be expected to be a slow process, with oil penetration in the water column increasing with time, and sediment transport processes carrying oil-laden beach sediment into the sub-littoral zone.

A calculation of a 'budget' for the spilled oil indicates the major pathways were as follows:

spilled oil:	15 m^3
oil cleaned up by Coast Guard:	6.2 m^3
oil evaporated in 48 hrs:	2.4 m^3
oil in water column:	0.26 m^3 (assuming 6 flushes of area)

oil in sediment and organisms:	0
oil on beach:	5.6 m^3 (from total hydrocarbon measurements)
unaccounted for:	0.5 m^3

In conclusion, the bulk of the oil which was not cleaned up stayed on the beach, with evaporation being the dominant weathering process. Impact of oil on the benthic transects was, in this initial phase of observations, not measurable by the instrumentation used.

TABLE 9.1: SURFACE OIL SPILL

SUMMARY OF EXPOSURES TO OIL

BAY	LOCATION	DEPTH (m)	EXPOSURE (ppm-h)
11	SS1	1 m	2.1
		3 m	N.D.
		5 m	N.D.
	SS2	1 m	1.2
		3 m	N.D.
		5 m	N.D.

Note:

1. Calculations are based on approximately 36 hrs of observation.
2. N.D. = not detectable. Detection limit is 0.25 ppm-h.

9.2 Dispersed Oil Spill

The dispersed oil spill began at 1300, 27 August, 1981. Fifteen metric tons of Lagomedio crude oil mixed 10% with dispersant was pumped as a 5:1 seawater:oil mix out through a diffuser pipe at the south end of the experimental area in Bay 9. Because of the rather complex physical oceanographic regime in the bay, what happened next depended on the depth at which the oil was released.

Shallow oil, or oil released from the diffuser pipe between 3 and 7 m depth, moved with the gyre or eddy current in the bay. This oil was carried south to the far end of Bay 9, then back around, eventually reaching the experimental area six hours after the start of pumping (see Figure 9.1). This extended preliminary journey actually was advantageous since it allowed the oil to spread into an even cloud prior to reaching the test site.

The deep oil, or oil released between 8 and 15 m, behaved very differently. It became entrained in the northward-flowing 'coastal jet' current. Some of this oil caught the corner of the experimental site, inundating the south microbiology station with concentrations in excess of 150 ppm, cutting across the southern half of the 7 m transect, and just reaching the 6 m Baffin Queen raft station. Some of this oil circulated into Bay 9 proper, but much continued past and either circulated into Bay 10 or moved off into Ragged Channel (see Figure 9.1).

Both shallow and deep oil movements apparently stagnated during the evening when the tide was flooding, then the bay flushed out on the following tidal cycle. The resulting exposures of the various monitoring stations are summarized in Table 9.2. The monitoring stations averaged about 300 ± 100 ppm-h, with maximum concentrations of 50 ppm. The exception was the pump at the south microbiology station which was directly in the path of the deep oil moving north. There the oil exposure was 880 ppm-h and the maximum recorded concentration was 167 ppm. A gradation of biological effect is therefore to be expected along the deep transect in Bay 9 and between the south and north microbiological stations.

Bay 10 also received a considerable amount of dispersed oil. During the ebb tide in the early morning, 28 August, moderately high concentrations of oil (5 - 7 ppm) moved through Bay 10, and for much of the monitoring period concentrations around 0.5 ppm were observed. The calculated exposure of Bay 10, based on rather limited data from the profiles, was 30 ppm-h or about one order of magnitude less than Bay 9.

The dispersed oil continued to spread until, on the fourth day (30 August), it could be found throughout Ragged Channel at levels of 30-50 ppb at depths of 5 to 15 m. Both Bay 7 and Bay 11 were exposed to these low levels of hydrocarbons, resulting in 36 hour exposures of about 0.5 ppm-h, three orders of magnitude below Bay 9.

These observations are supported to varying degrees by several analytical data sets in Volume 2 of this report (Boehm et al., 1982). In particular, the low molecular weight hydrocarbon analyses of water samples correlate well with the general circulation of the dispersed oil described above, and the large volume water sampling program confirms that low levels of hydrocarbons spread throughout Ragged Channel in the days after the dispersed oil spill.

On the fourth day all of the spilled oil could be accounted for as a concentration of 35 ppb dispersed oil in a layer 10 m thick spread throughout Ragged Channel. A 'budget' for the spilled oil is as follows:

spilled oil:	15 m^3
cleaned up:	0.1 m^3
evaporated:	0
oil on beach:	0
oil in sediment, tissue:	0.015 m^3
dispersed in water column:	15 m^3 (35 ppb x 10 m deep layer x area Ragged Channel)
unaccounted for:	0

The contrast with the surface spill is dramatic. For the surface spill, major pathways were for the oil to remain on the beach, evaporate, or be cleaned up. None of these pathways were significant for the dispersed oil spill, whose fate was almost entirely water column dispersal.

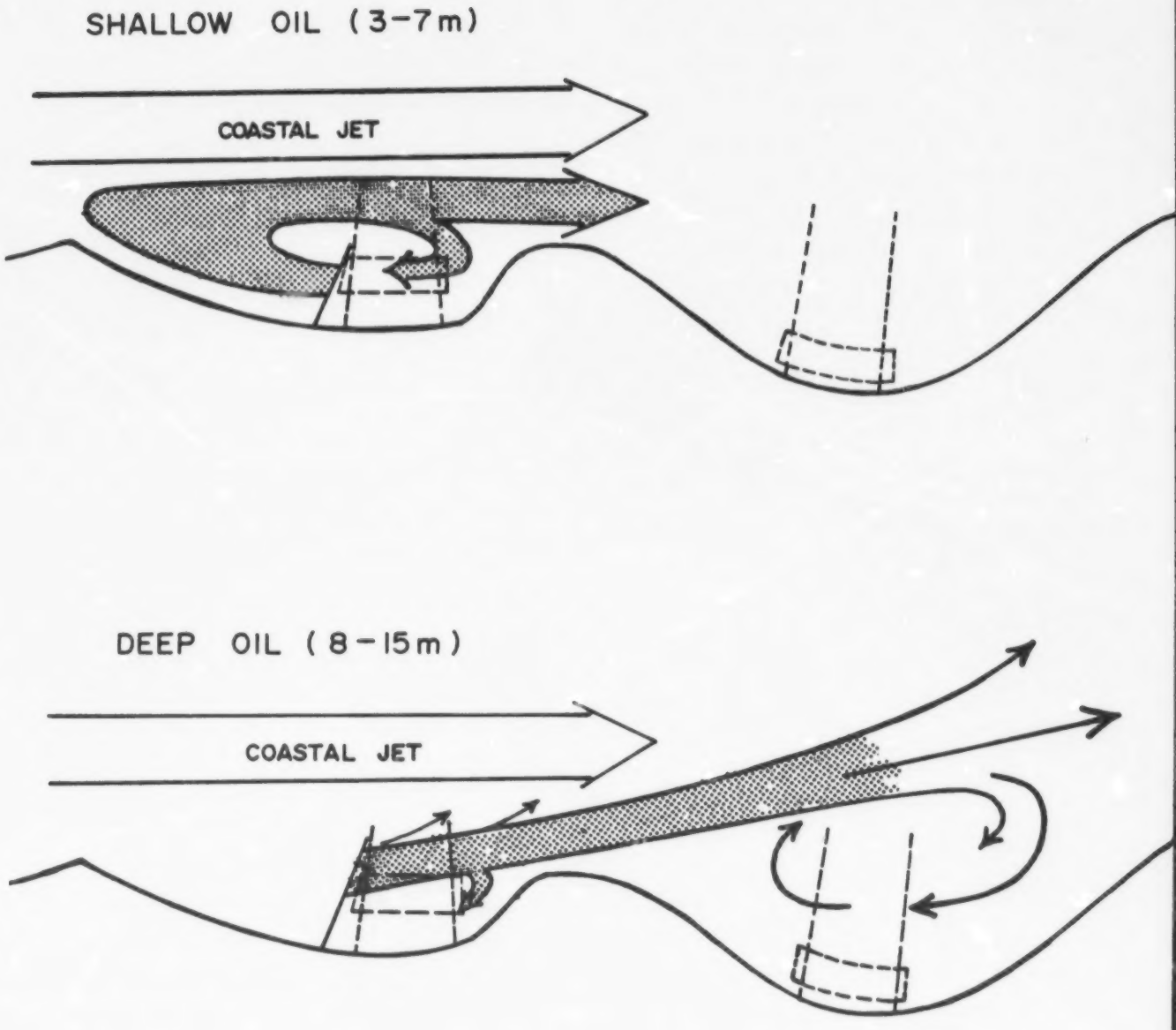


Figure 9.1 A Sketch of Oil Movements for the First Six Hours of the Dispersed Oil Spill.

TABLE 9.2 DISPERSED OIL EXPERIMENT SUMMARY OF EXPOSURES TO OIL

DISPERSED OIL EXPERIMENT

BAY	LOCATION	DEPTH (m)	EXPOSURE (ppm-hrs)
9	SS1	1 m	185
		6 m	324
		8 m	336
	SS2	3 m	229
		7 m	PUMP FAILURE
		10 m	878
	BQ	0 m	29
		2 m	20
		4 m	96
		6 m	410
10		3 m	37
		7 m	30
		10 m	10
7		3 m	0.3
		7 m	1.2
		10 m	0.5

Notes: 1. Calculations are based on approximately 36 hrs of observation.

2. Values for Bays 7 and 10 are based on intermittent profiles. Remainder are from continuous flow monitoring stations.

10. CONCLUSIONS

The contrast between the two experimental spills was dramatic. For the surface oil spill, virtually all of the oil reached the beach or was collected by mechanical means, and evaporation was the dominant weathering process.

For the dispersed oil experiment, nearly all of the oil remained in the water column. Dispersion of the oil was the dominant weathering process. The chemical dispersant was very effective at promoting dispersion and preventing oil from reaching the shoreline.

11. REFERENCES

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Dickins, D.L. 1982. Baffin Island Oil Spill Project: Oil Discharge Systems 1981.

Guilbault, G.G. 1973. Practical Fluorescence. Marcel Drekker Inc., New York.

Owens, E.H.; J.R. Harper; C.R. Foget. 1982. Baffin Island Oil Spill Project: 1981 Shoreline Component.

12. APPENDICES

12.1 APPENDIX A: Detailed Time Series Plots of Oil Concentrations from the Dispersed Oil Spill

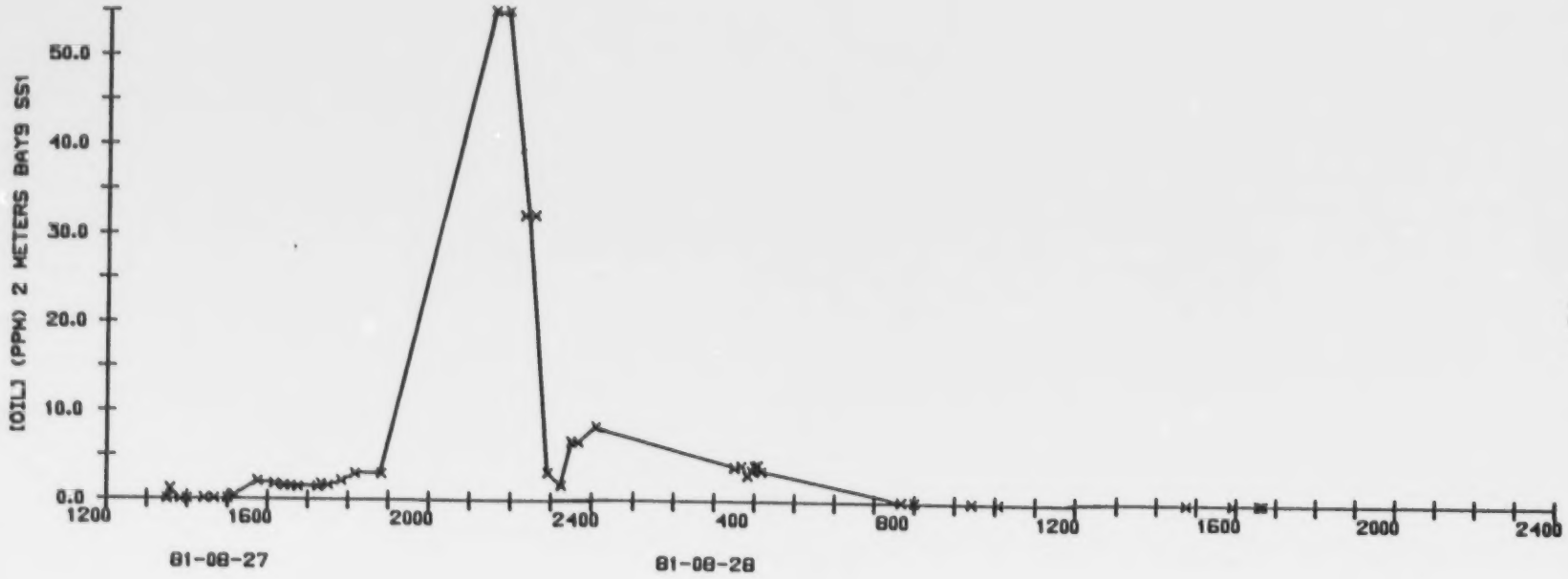
Notes:

1. The time series plots are arranged as follows:

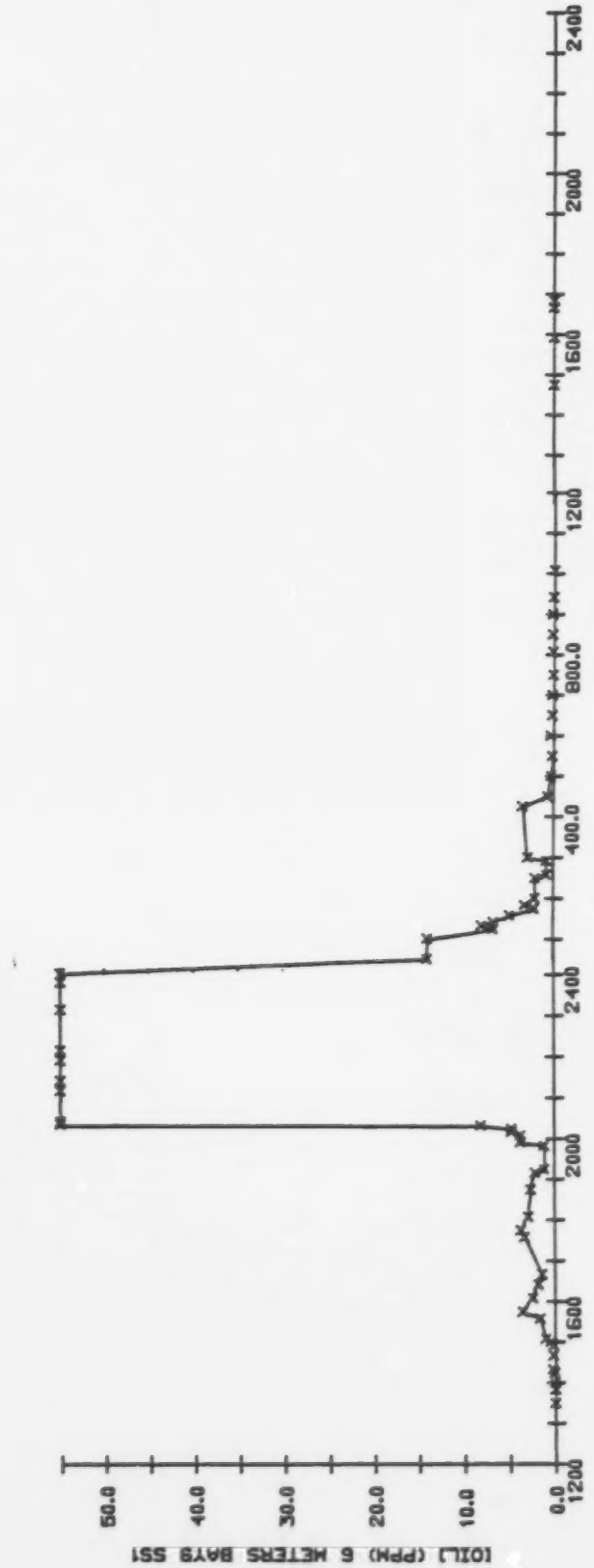
Bay 9	Shore Station 1	2, 6, 8 m
	Shore Station 2	3, 7, 10 m
	Baffin Queen	0, 2, 4, 6 m
Bay 10		3, 7, 10 m

2. The Bay 10 time series plots are produced from profile data. No continuous monitoring equipment was deployed there.

3. Data points indicated by circles are from laboratory analyses of grab samples.



BAY 9, SHORE STATION 1, 2 METERS



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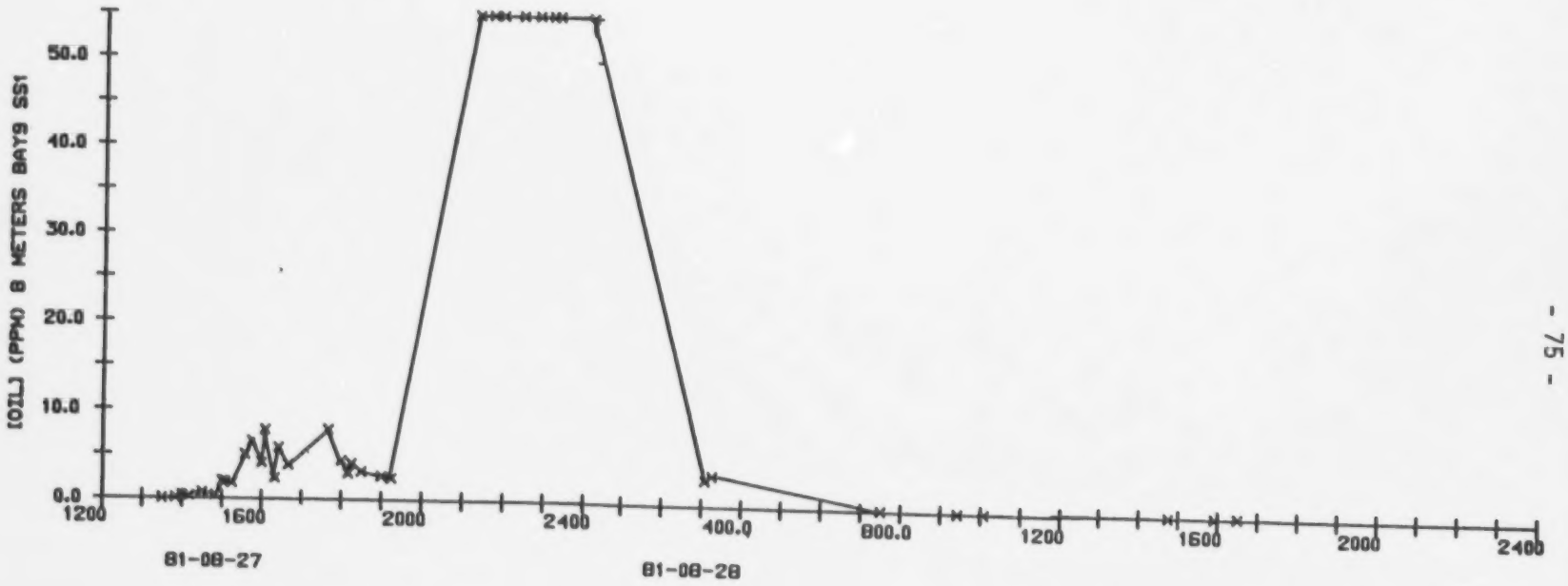

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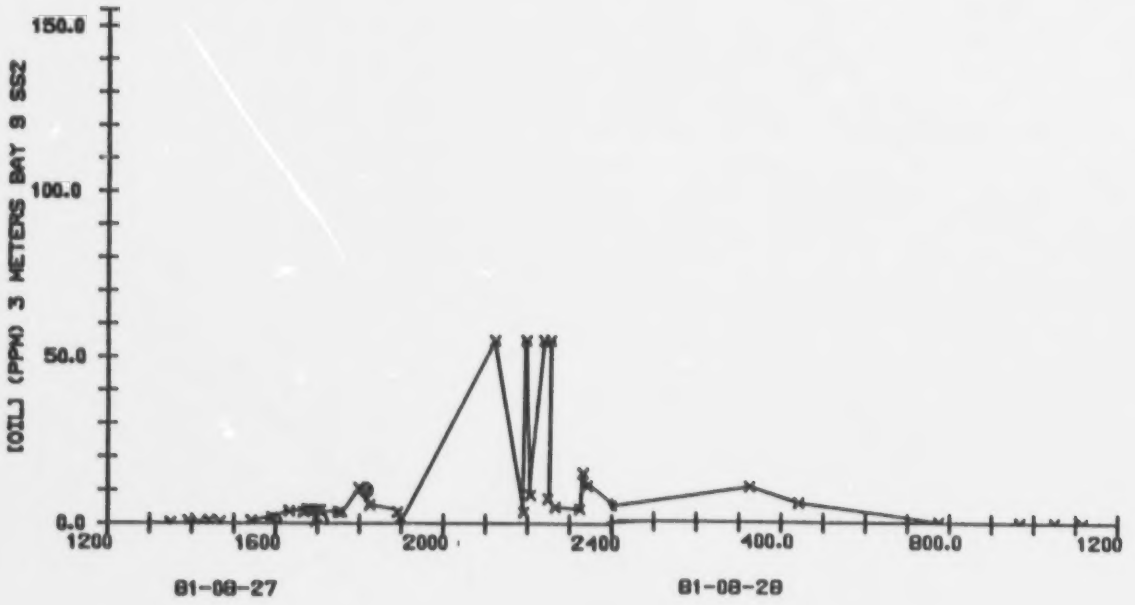

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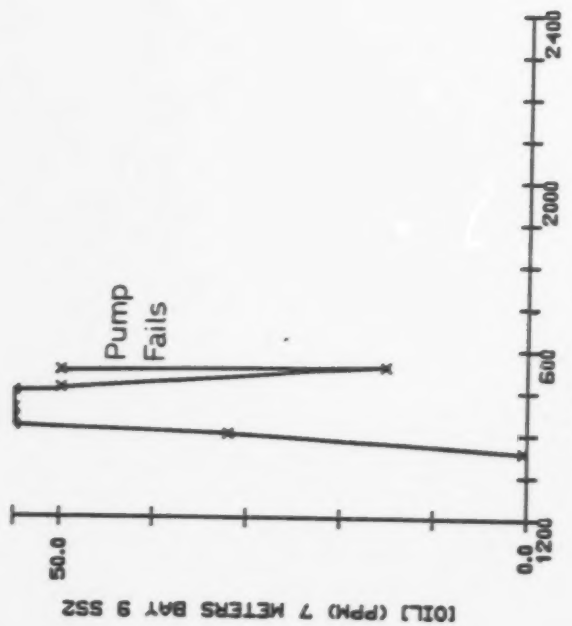

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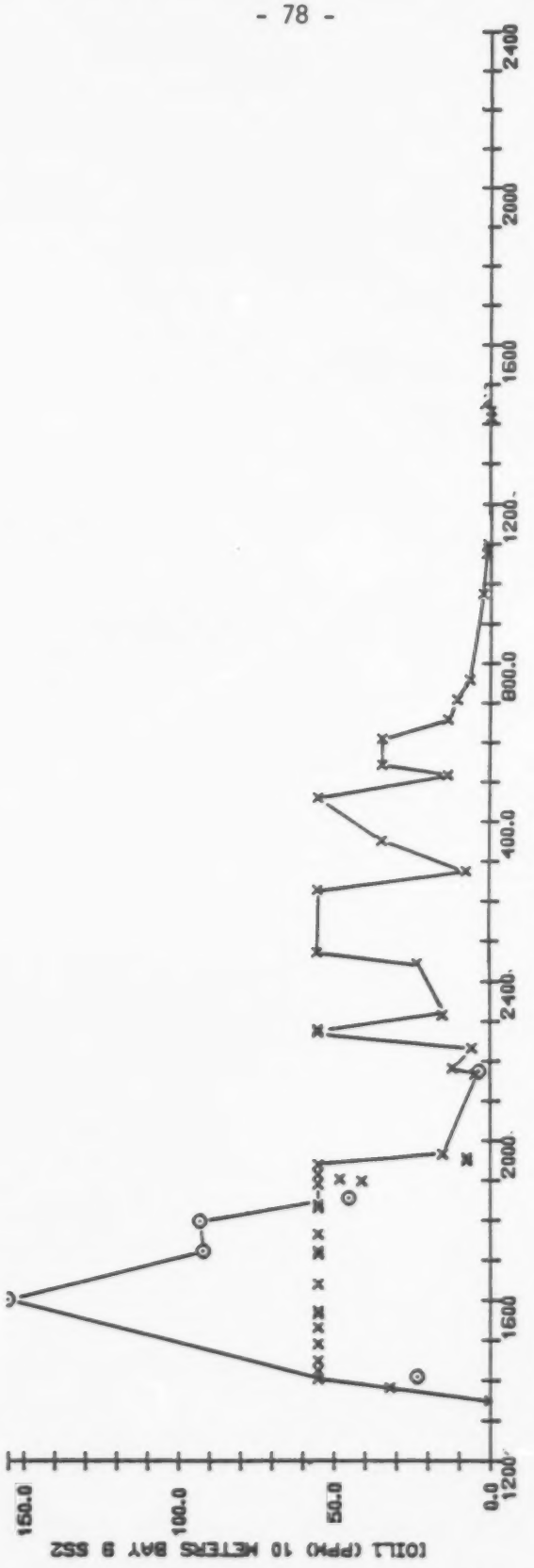

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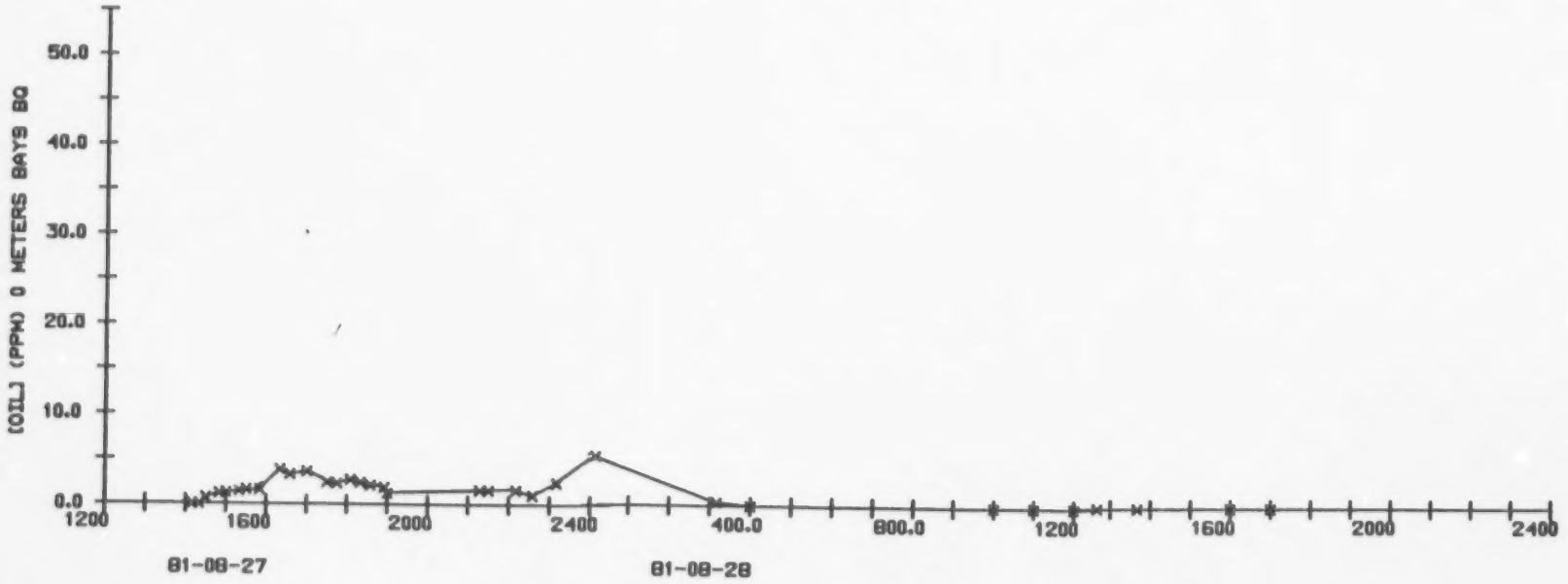

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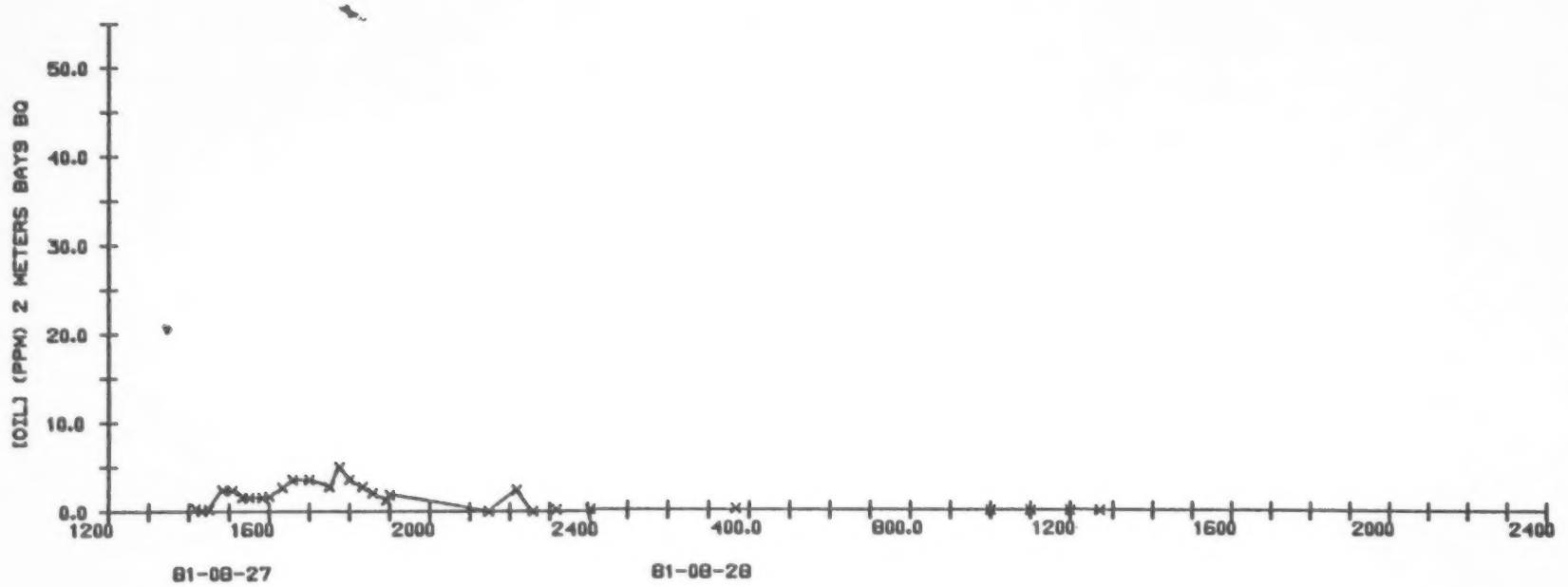

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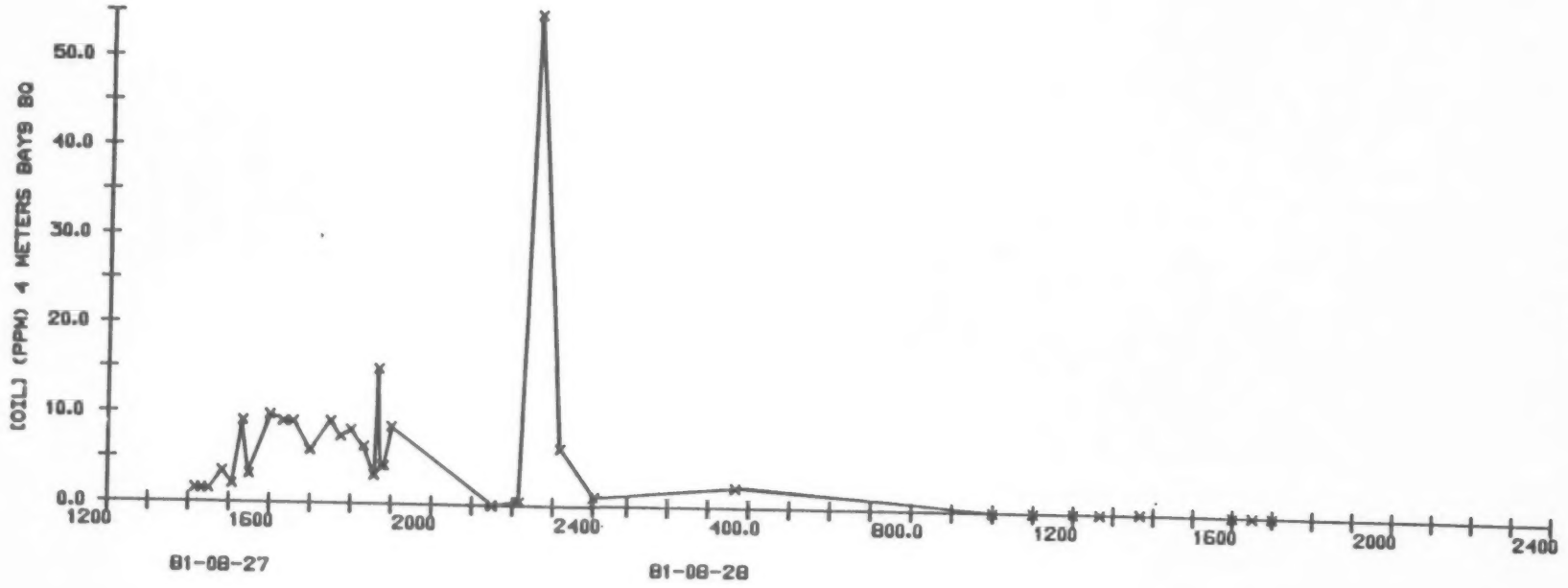

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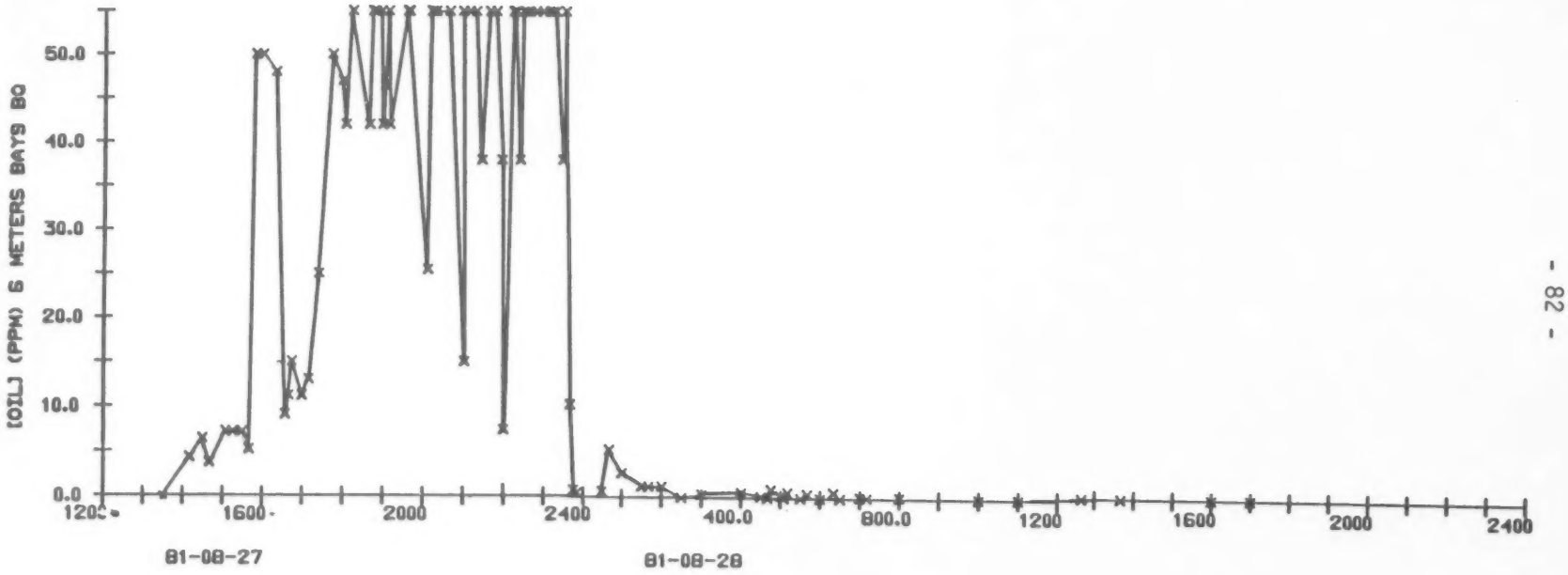

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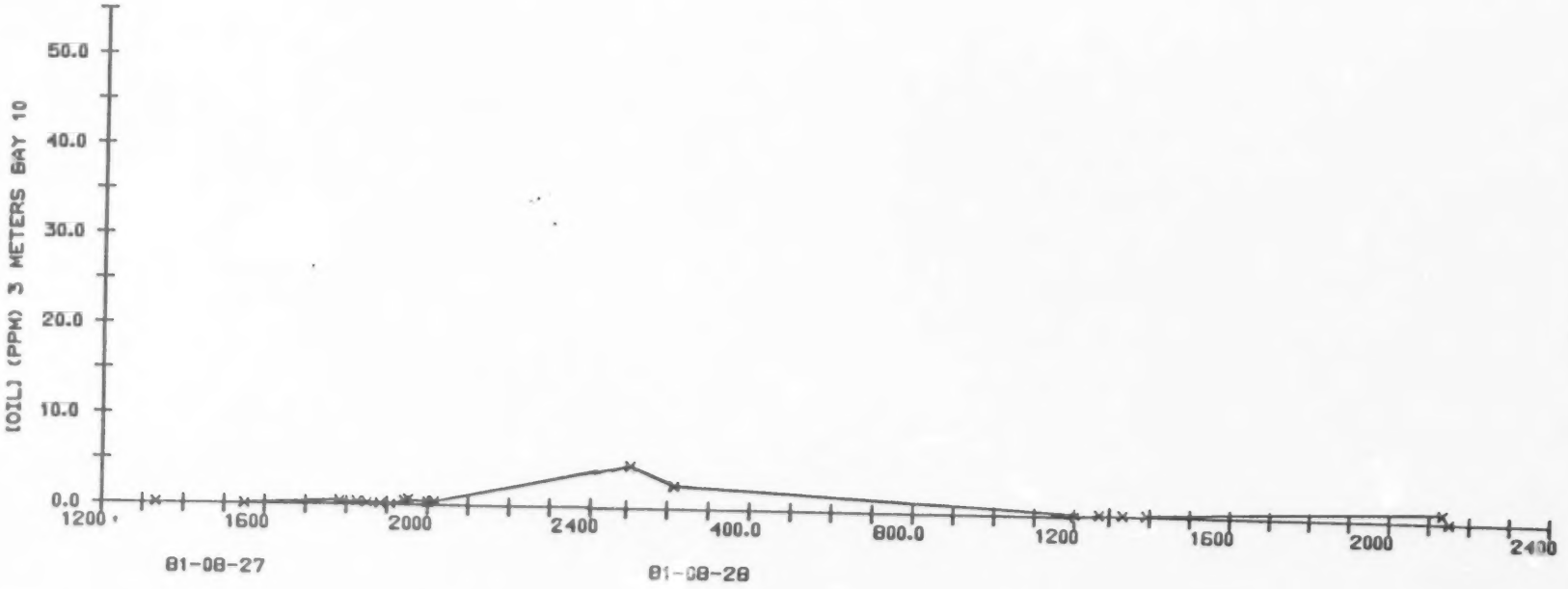
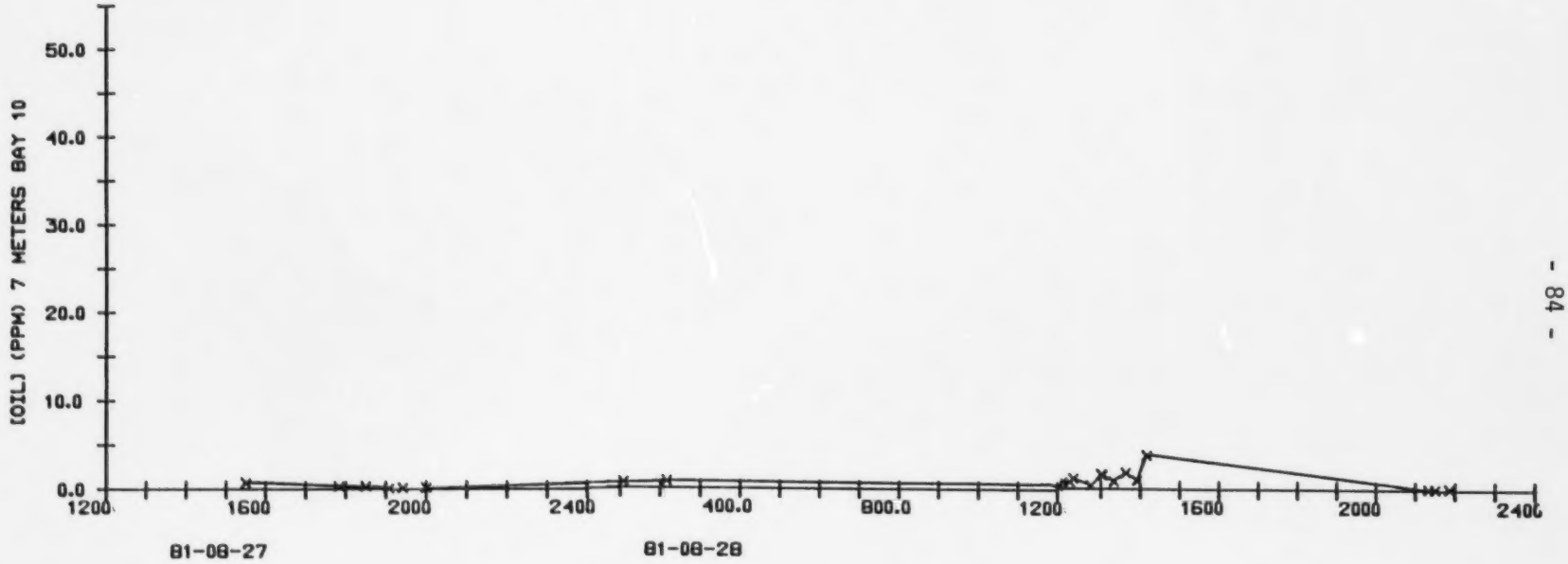


BAY 10, 3 METERS



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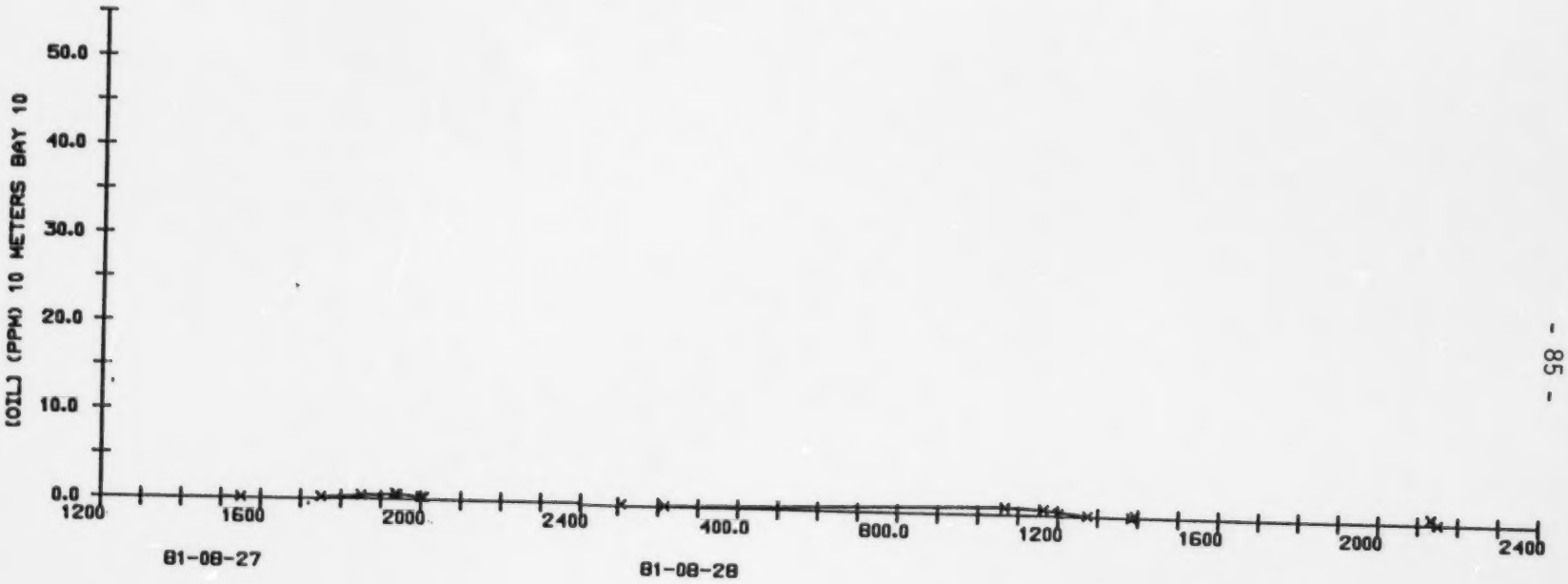


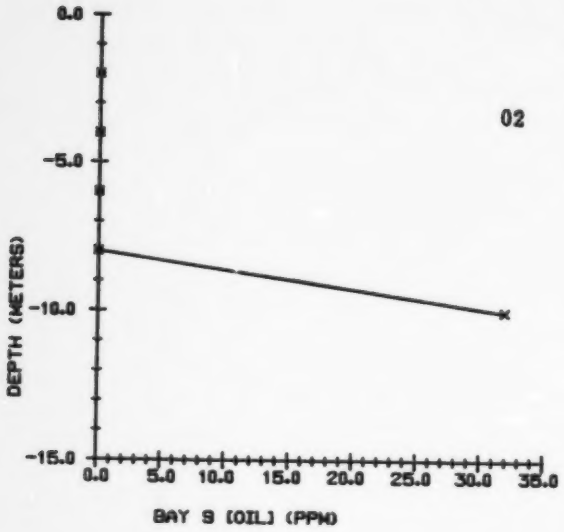
BAY 10, 10 METERS

12.1 APPENDIX B: Vertical Profiles of Oil Concentration During and After the Dispersed Oil Spill

In the following pages vertical profiles from the dispersed oil spill are presented. They are in chronological order, and the title with each follows the format:

identity number; bay; location; day; time.

Error bars indicate the spread of readings obtained at one depth.



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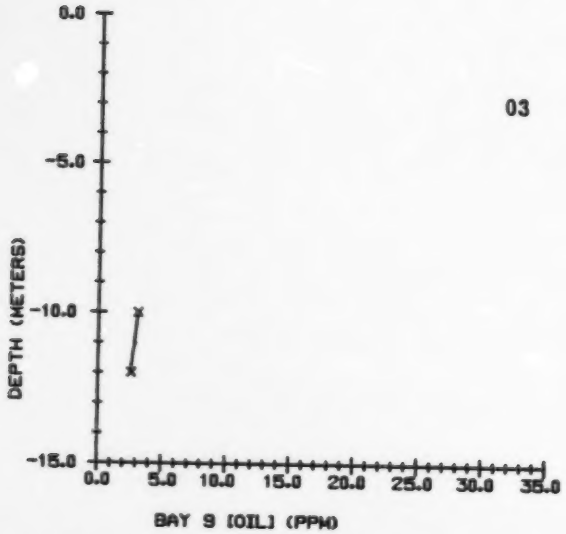

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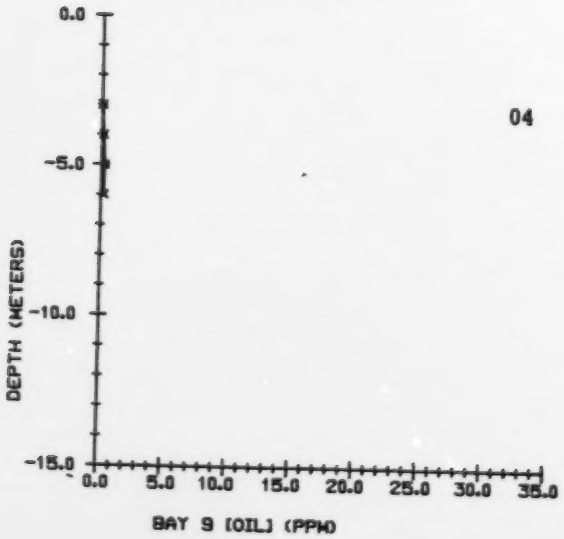

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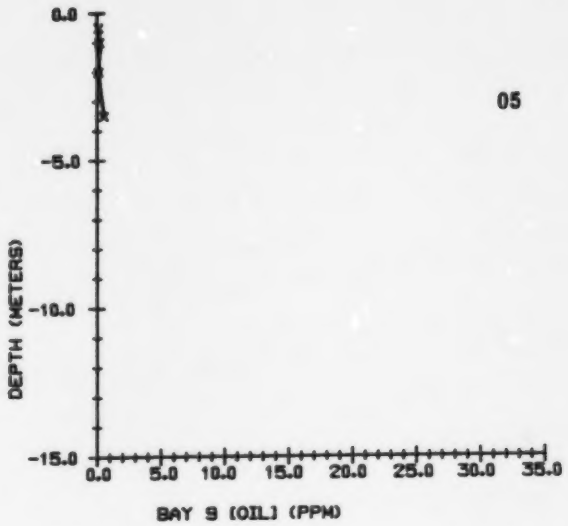

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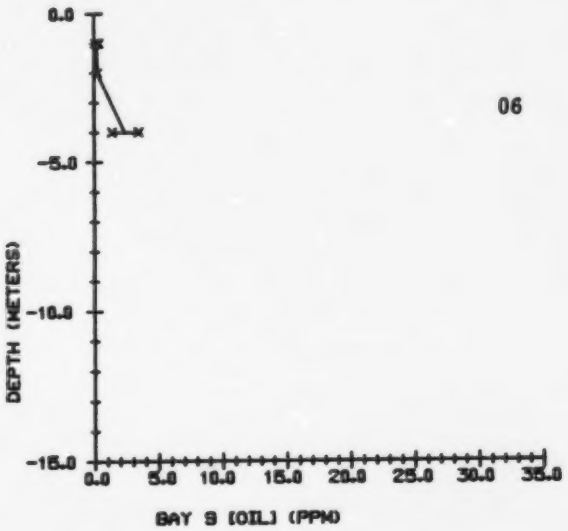

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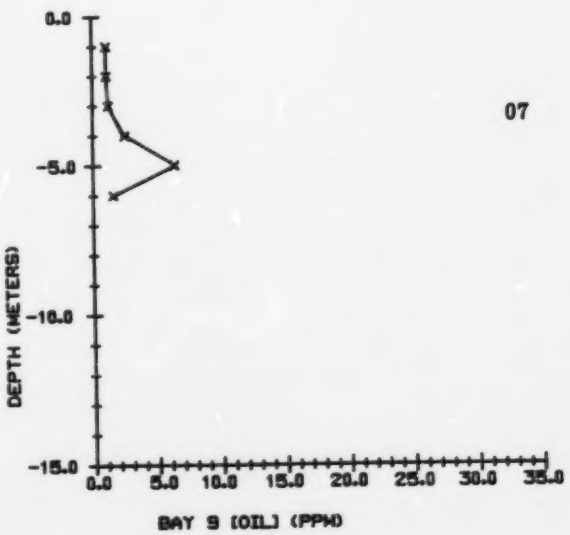

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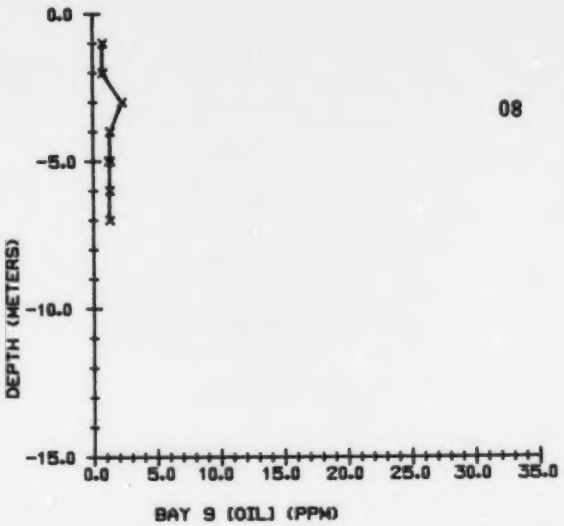

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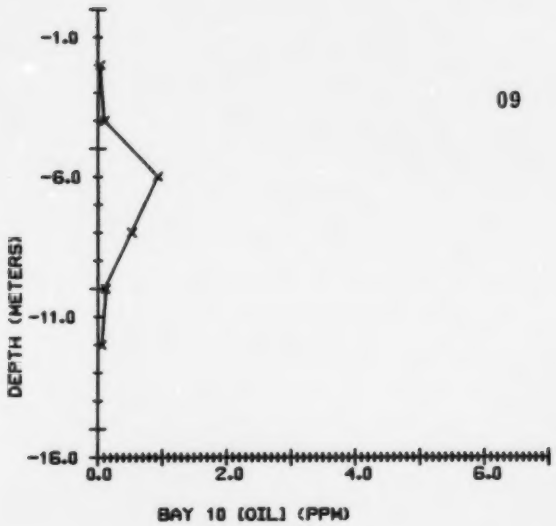

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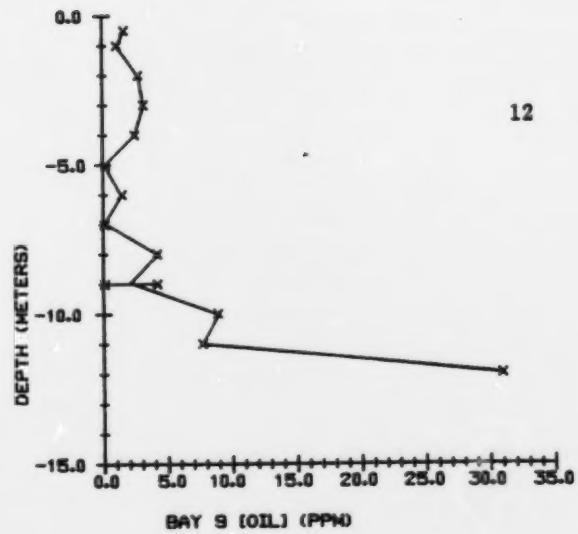

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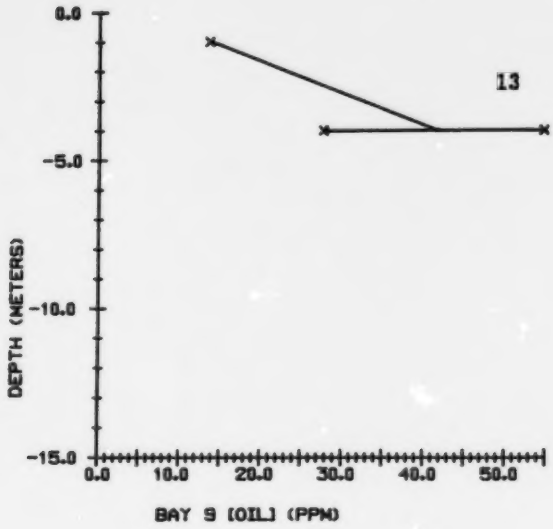

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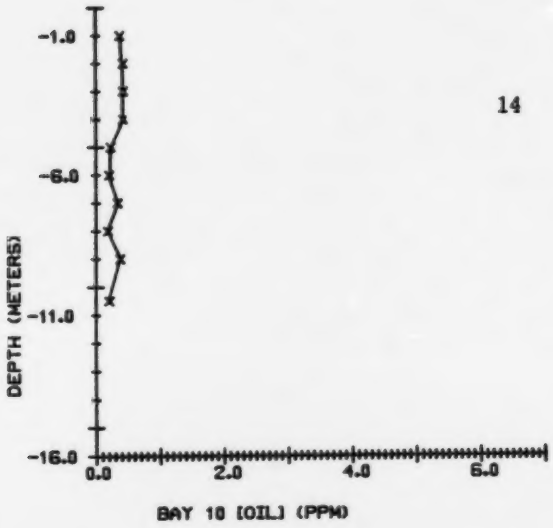

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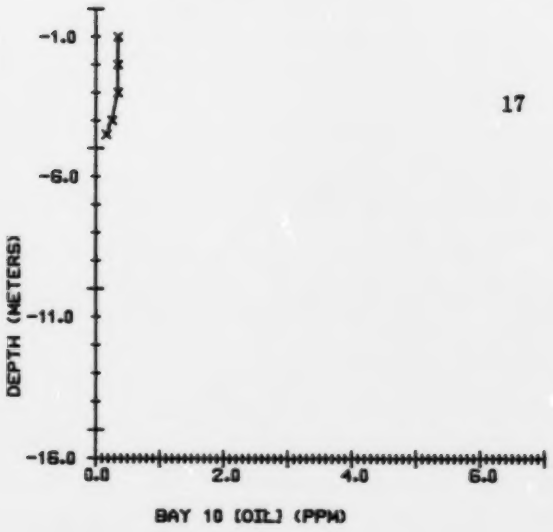

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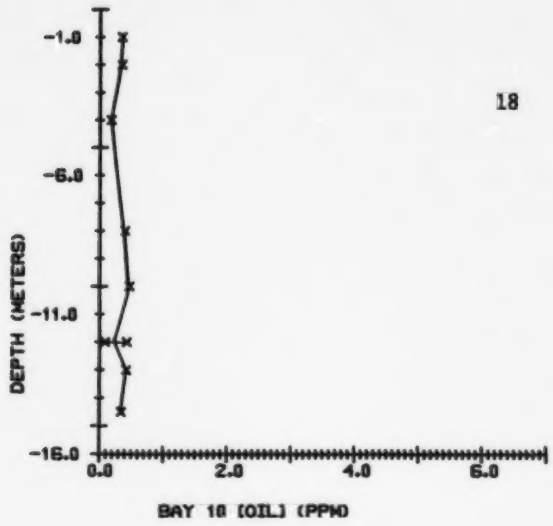

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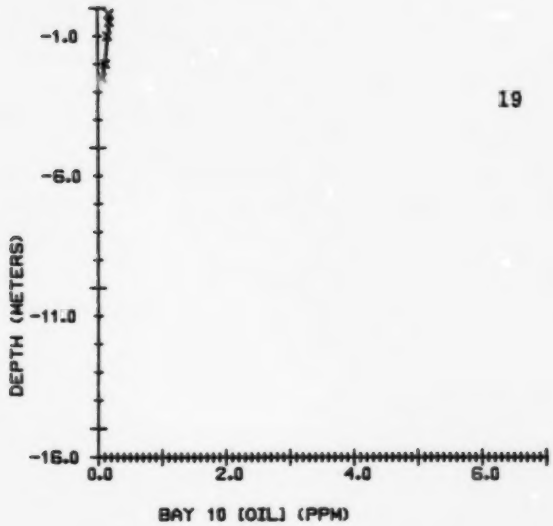

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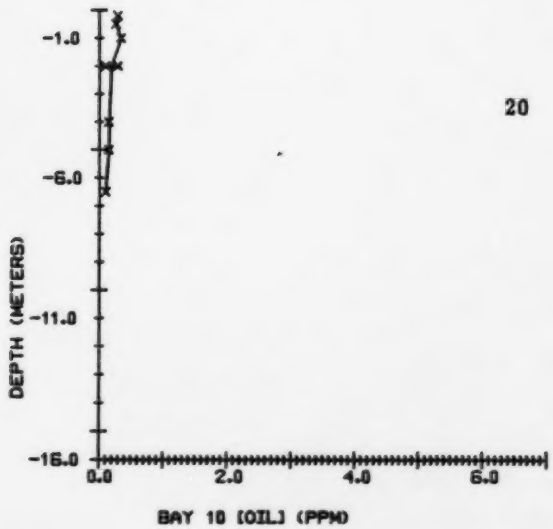

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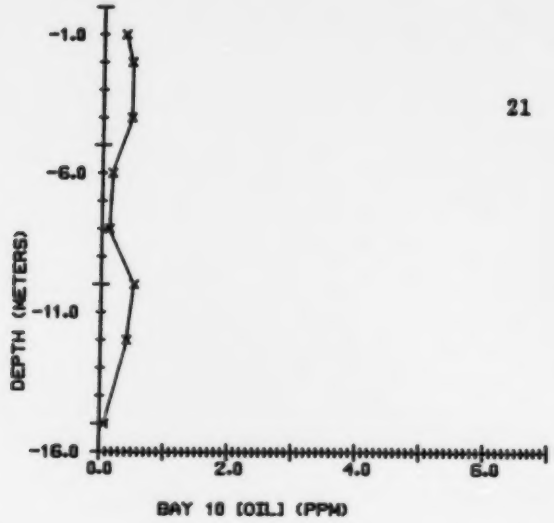

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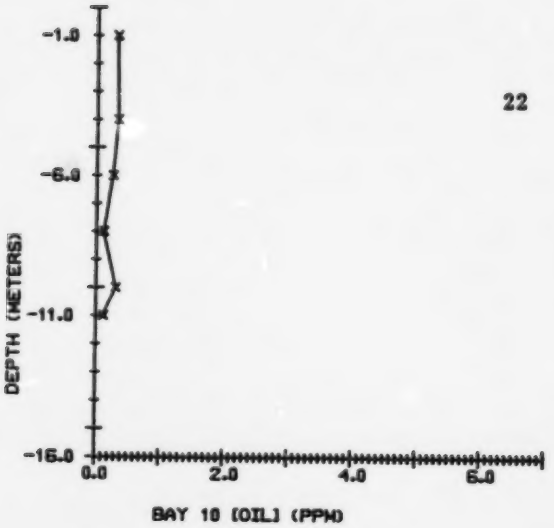

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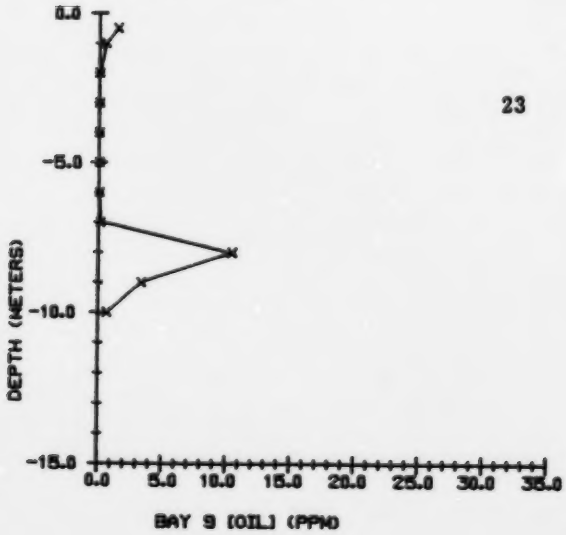

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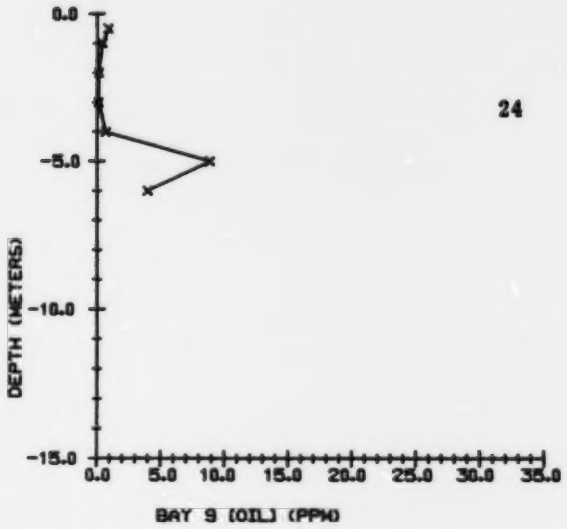

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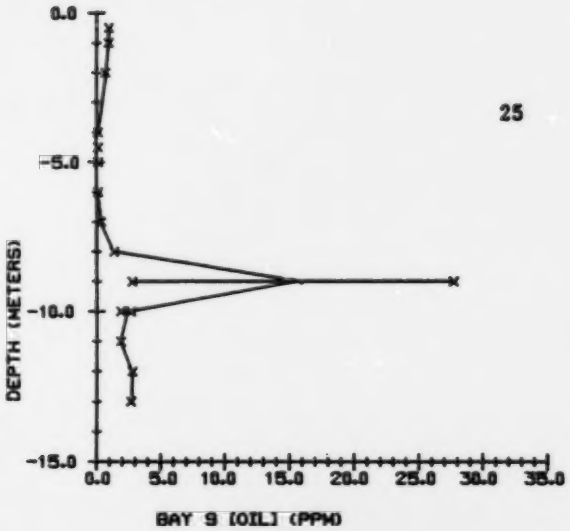

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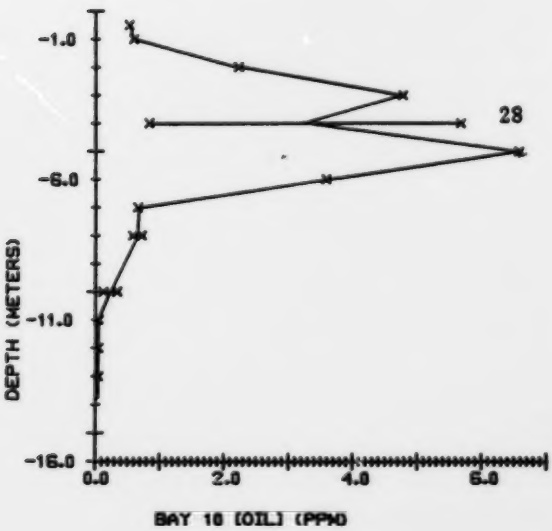

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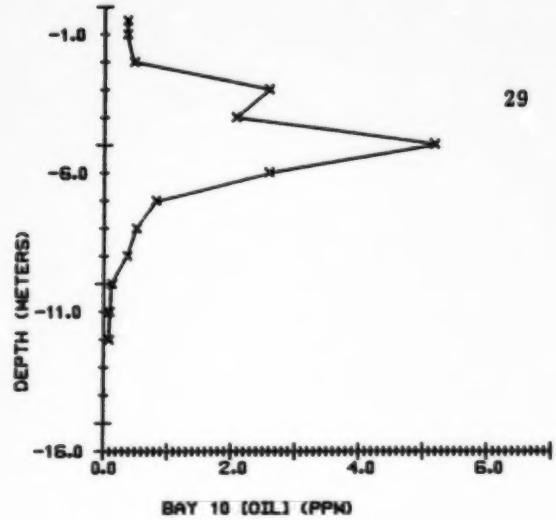

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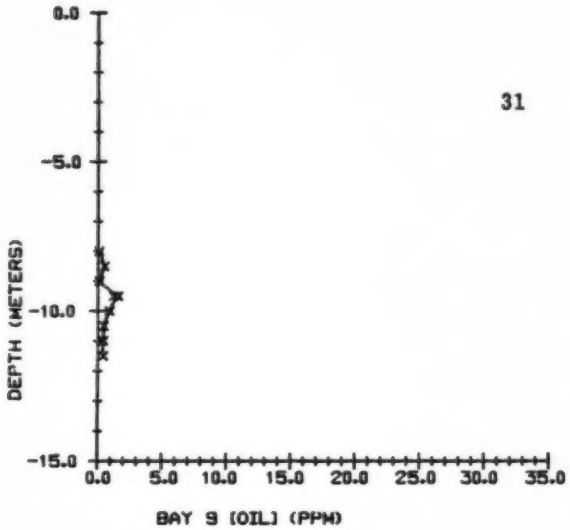

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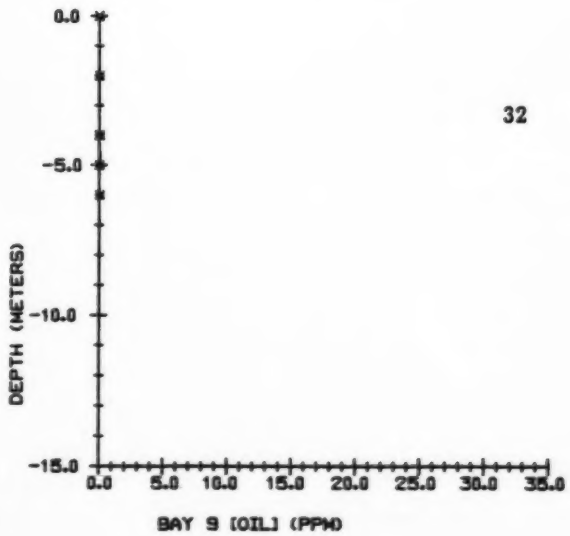

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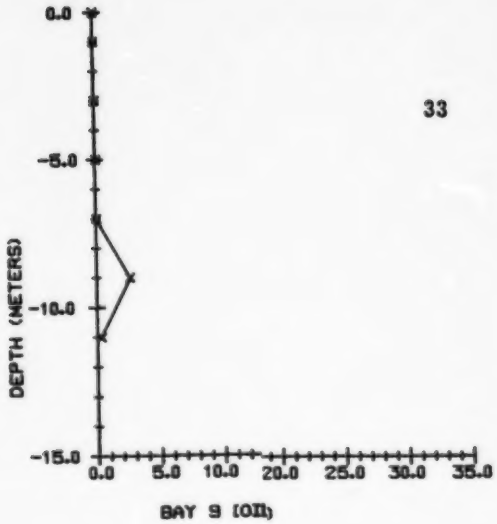

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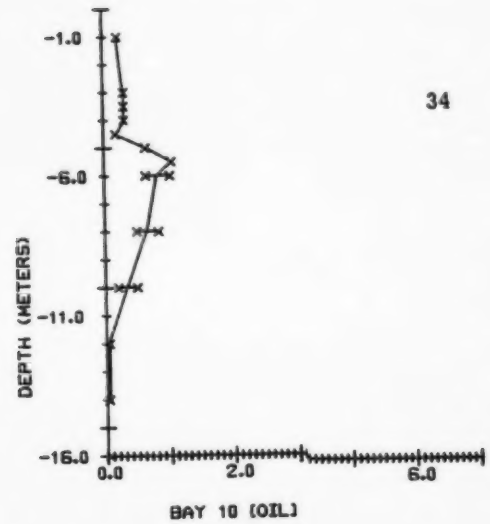

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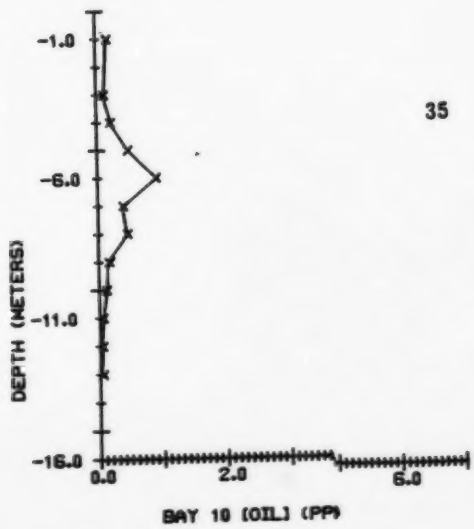

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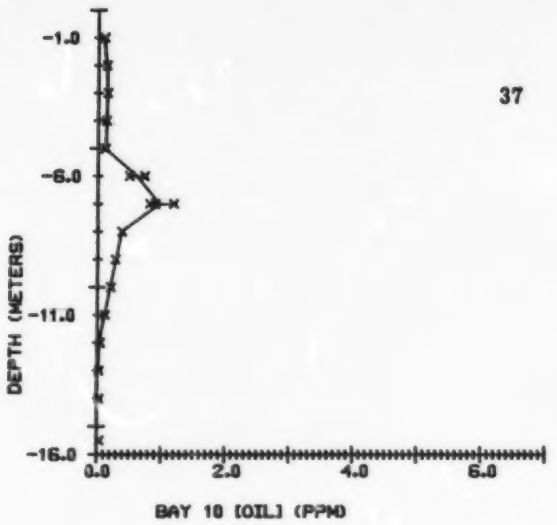

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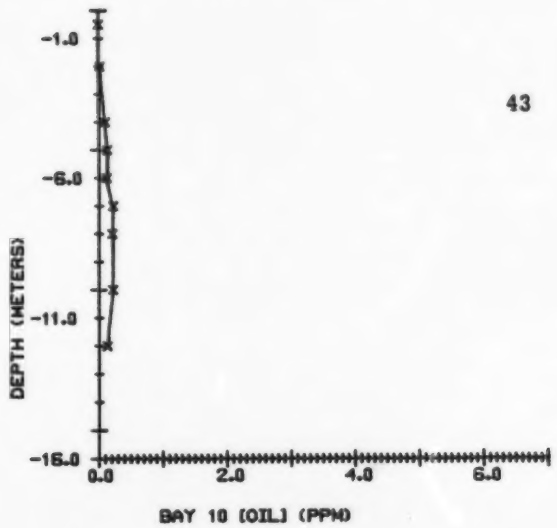

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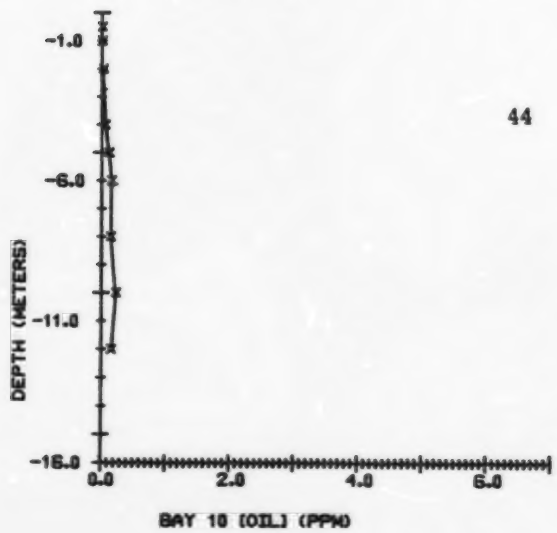

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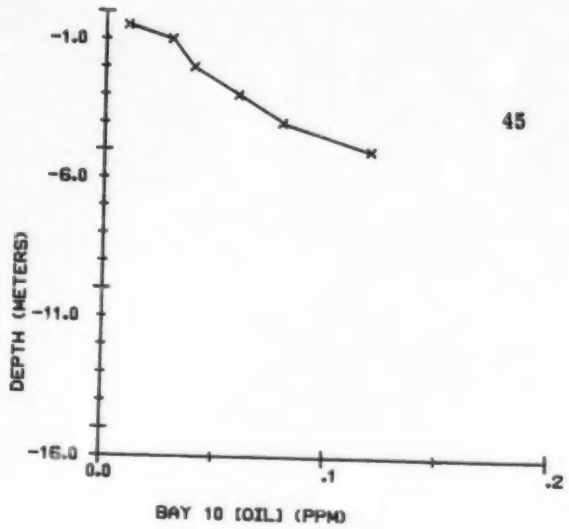

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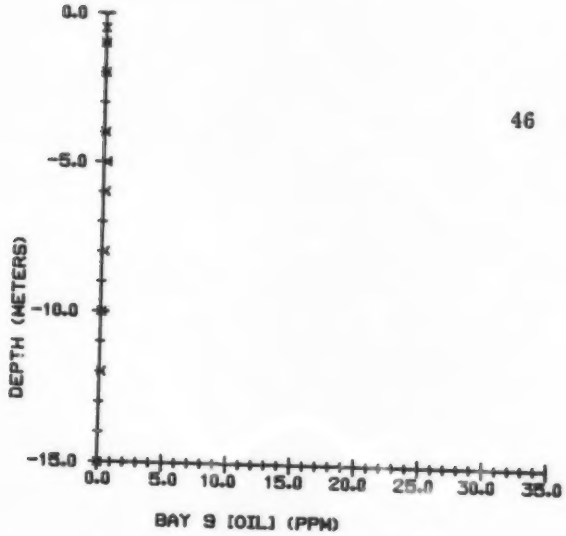

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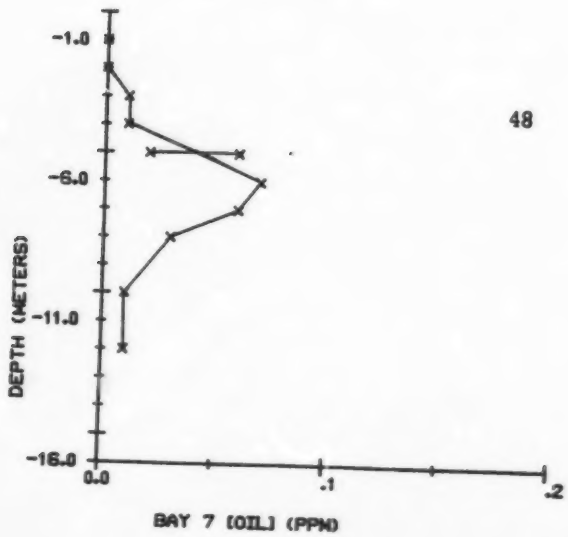

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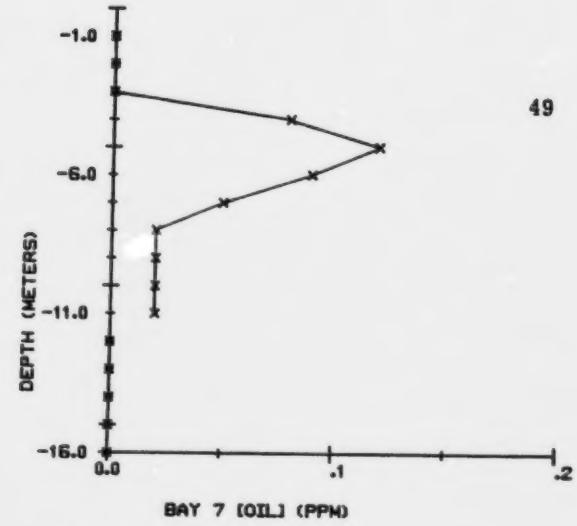

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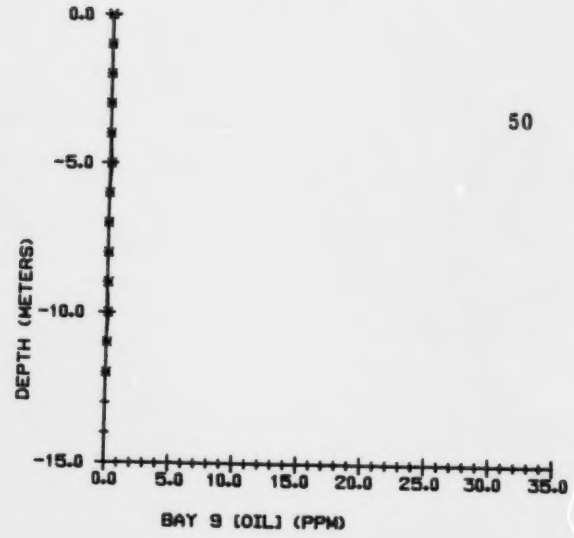
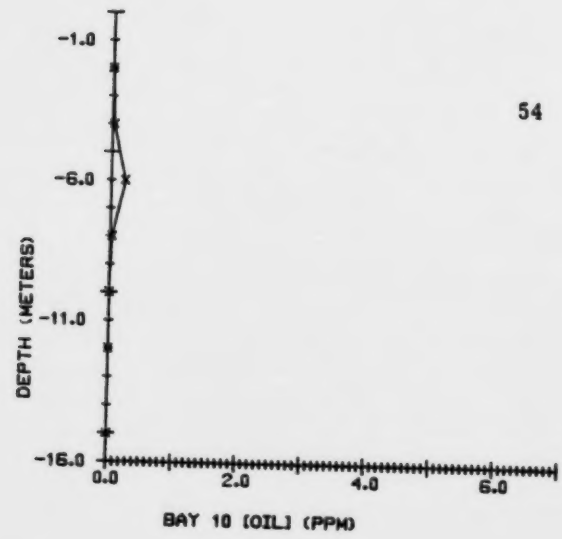
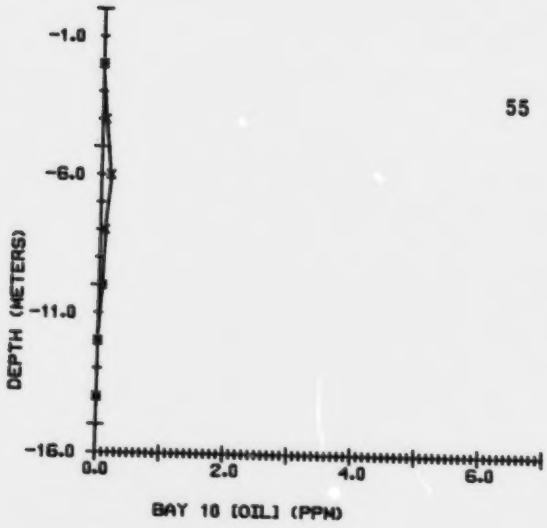


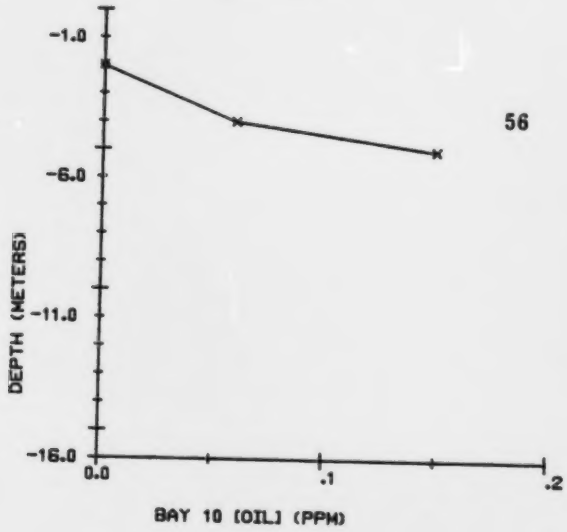
50 9 S MICRO 29/1334



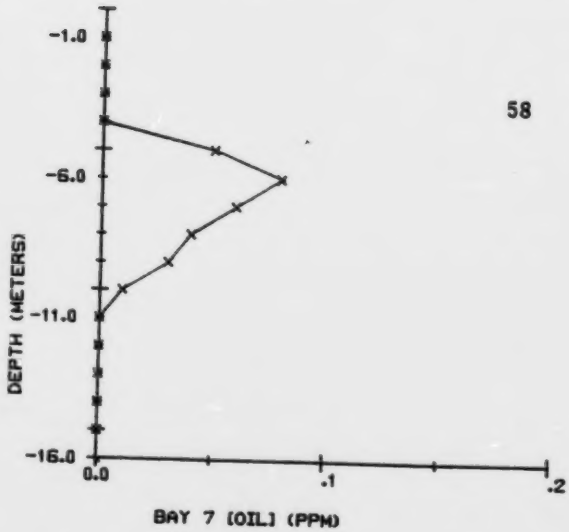
54 10 S MICRO 28/2120



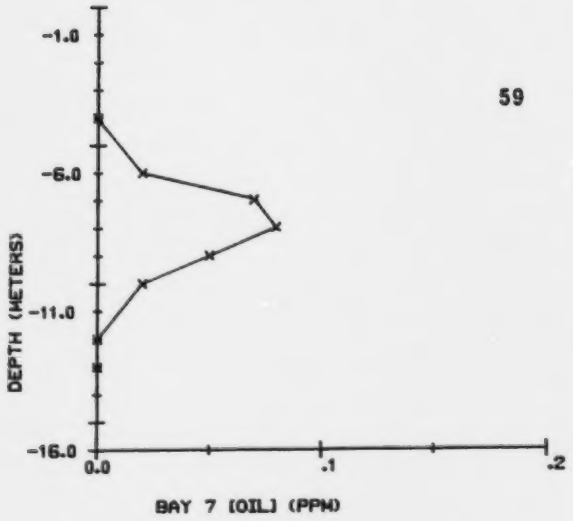
55 10 N MICRO 28/2130



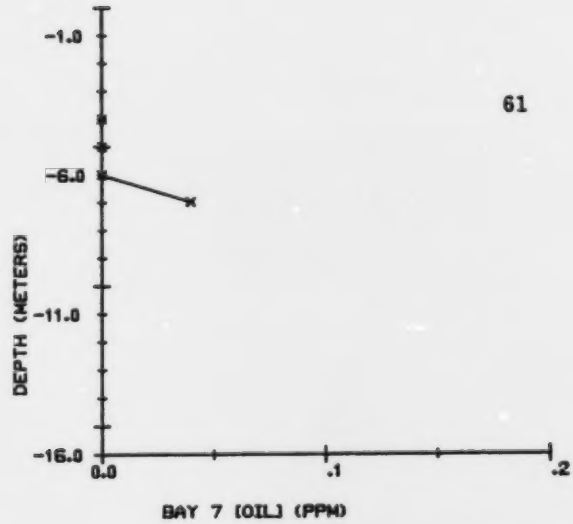
56 10 BQ 28/2150



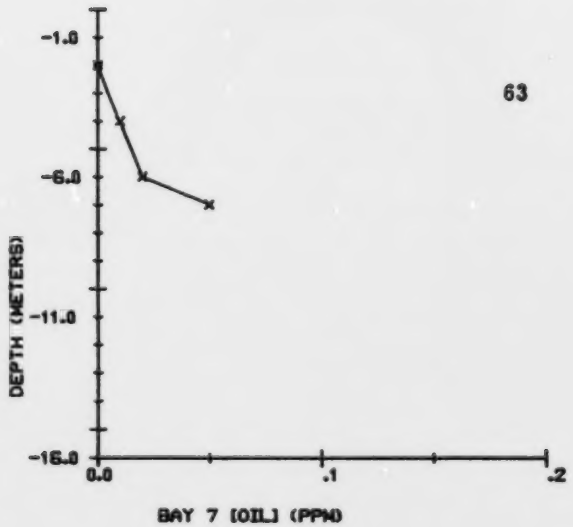
58 7 29/1645



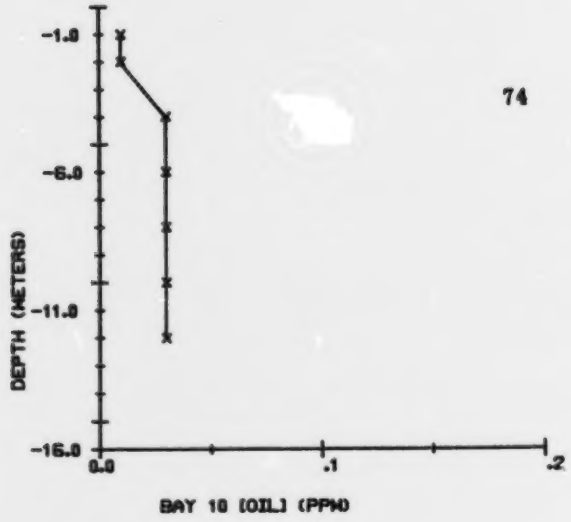
59 7 29/1700



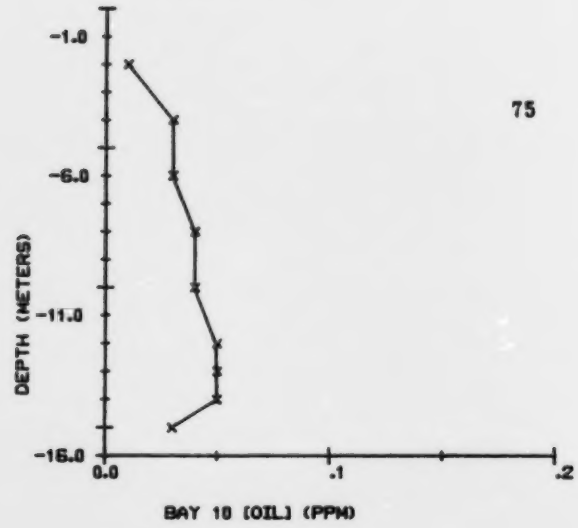
61 7 N TRAN 7M 29/1720



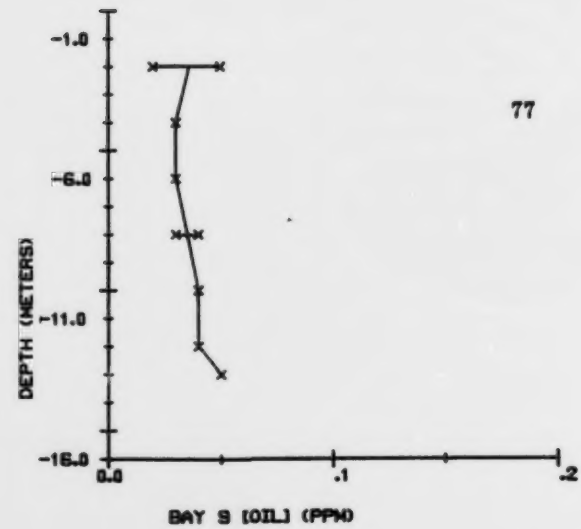
63 7 S TRAN 7M 29/1730



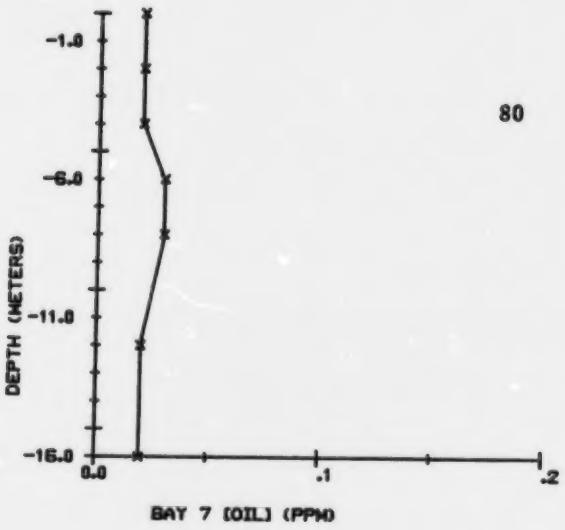
74 10 N MICRO 30/1350



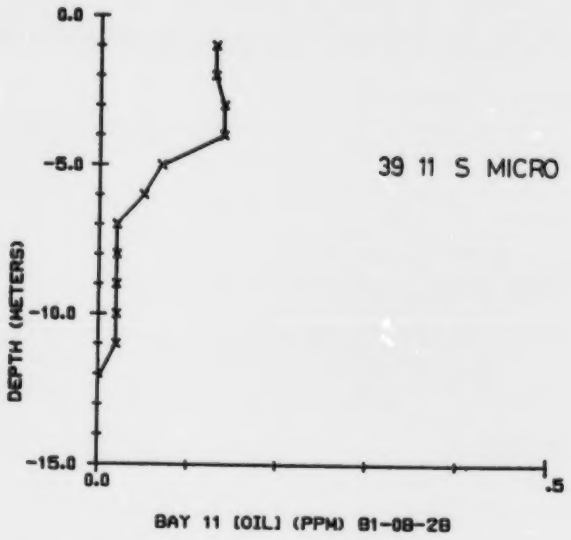
75 10 S MICRO 30/1410



77 9 N MICRO 30/1445

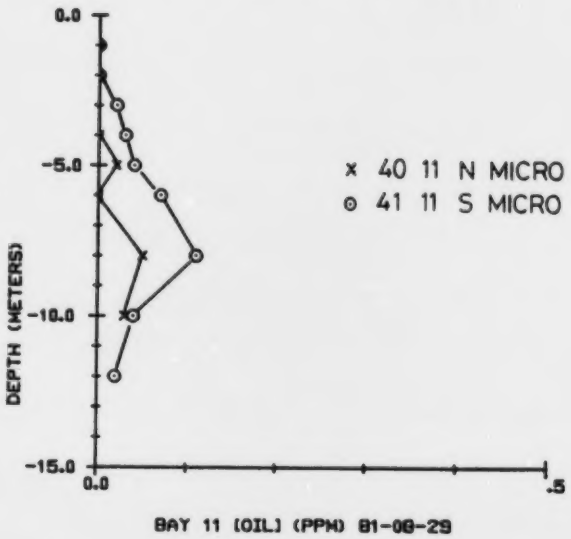


80 7 30/1655



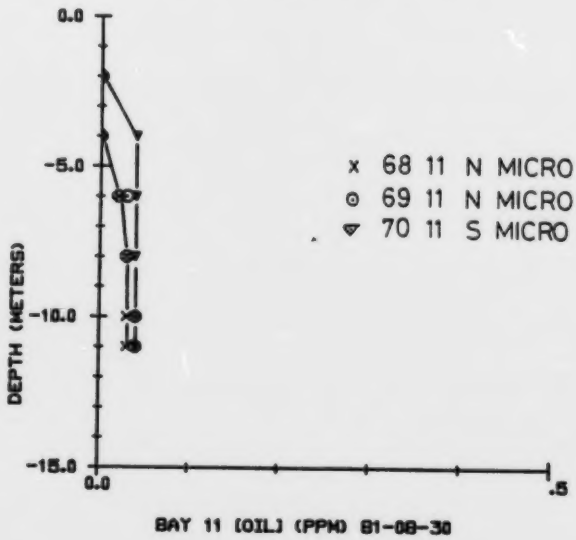
39 11 S MICRO 28/1505

BAY 11 (OIL) (PPM) 81-08-28



x 40 11 N MICRO 29/0940
⊙ 41 11 S MICRO 29 0957

BAY 11 (OIL) (PPM) 81-08-29



x 68 11 N MICRO 30/1221
⊙ 69 11 N MICRO 30/1240
▽ 70 11 S MICRO 30/1250

BAY 11 (OIL) (PPM) 81-08-30

12.3 APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
041	TE1 Surface	81-07-28	29,000
042	TE1 Subsurface	81-07-28	24,000
017	H1 Upper Surface	81-07-28	150
018	H1 Upper Subsurface	81-07-28	1,460
019	H1 Mid Surface	81-07-28	trace
020	H1 Mid Subsurface	81-07-28	trace
023	H2 Upper Surface	81-07-28	3,630
024	H2 Upper Subsurface	81-07-28	770
025	H2 Mid Surface	81-07-28	0
026	H2 Mid Subsurface	81-07-28	0
027	H2 Low Surface	81-07-28	0
028	H2 Low Subsurface	81-07-28	0
001	L1 Upper Surface	81-07-28	4,790
002	L1 Upper Subsurface	81-07-28	5,770
003	L1 Mid Surface	81-07-28	2,920
004	L1 Mid Subsurface	81-07-28	7,470
005	L1 Low Surface	81-07-28	6,460
006	L1 Low Subsurface	81-07-28	1,820
007	L2 Upper Surface	81-07-28	70
008	L2 Upper Subsurface	81-07-28	trace
009	L2 Mid Surface	81-07-28	290
010	L2 Mid Subsurface	81-07-28	130
011	L2 Low Surface	81-07-28	50
012	L2 Low Subsurface	81-07-28	70

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.	DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
100.1, 0.2	TH-H1 Surface Upper	81-08-29	trace
101.1, 0.2	TH-H1 Upper Subsurface	81-08-29	0
102.1, 0.2	TH-H1 Mid Surface	81-08-29	0
103.1, 0.2	TH-H1 Mid Subsurface	81-08-29	0
104.1, 0.2	TH-H1 Low Surface	81-08-29	0
105.1, 01.2	TH-H1 Low Subsurface	81-08-29	0
106.1, 0.2	H2 Upper Surface	81-08-29	0
107.1, 0.2	H2 Upper Subsurface	81-08-29	0
108.1, 0.2	H2 Mid Surface	81-08-29	0
109.1, 0.2	H2 Mid Subsurface	81-08-29	0
110.1, 0.2	H2 Low Surface	81-08-29	0
111.1, 0.2	H2 Low Subsurface	81-08-29	trace
112.1, 0.2	L1 Upper Surface	81-08-29	2,520
113.1, 0.2	L1 Upper Subsurface	81-08-29	5,390
114.1, 0.2	L1 Mid Surface	81-08-29	1,090
115.1, 0.2	L1 Mid Subsurface	81-08-29	4,690
116.1, 0.2	L1 Low Surface	81-08-29	1,290
117.1, 0.2	L1 Low Subsurface	81-08-29	4,510
118.1, 0.2	L2 Upper Surface	81-08-29	170
119.1, 0.2	L2 Upper Subsurface	81-08-29	190
120.1, 0.2	L2 Mid Surface	81-08-29	170
121.1, 0.2	L2 Mid Subsurface	81-08-29	160
122.1, 0.2	L2 Low Surface	81-08-29	100
123.1, 0.2	L2 Low Subsurface	81-08-29	130

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.		DESCRIPTION		DATE SAMPLED	RESULT (mg/kg)
124	0.1, 0.2 0.3, 0.4	T1	Surface	81-08-29	34,000
125	0.1, 0.2 0.3, 0.4	T1	Subsurface	81-08-29	21,000
126	0.1, 0.2 0.3, 0.4	T2	Surface	81-08-29	16,000
127	0.1, 0.2 0.3, 0.4	T2	Subsurface	81-08-29	18,000
128.1		TE1	Surface	81-08-29	22,000
129.1		TE1	Subsurface	81-08-29	19,000
130.1		TE2	Surface	81-08-25	24,000
131.1		TE2	Subsurface	81-08-25	26,000

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.	DESCRIPTION			DATE SAMPLED	RESULT (mg/kg)
100	Bk-1	D(E)C	Upper 1/3	81-08-05	0
104	Bk-1	D(E)C	Lower 1/3	81-08-05	0
108	Bk-2	ME	Upper 1/3	81-08-05	trace
112	Bk-2	ME	Lower 1/3	81-08-05	0
116	Bk-3	MC	Upper 1/3	81-08-05	0
120	Bk-3	MC	Lower 1/3	81-08-05	trace
200,202 204,206	MC	Pretest Surface Composite		81-08-06	21,000
201,203 205,207	MC	Pretest Subsurface Composite		81-08-06	3,020
209,211 213,214b	ME	Pretest Surface Composite		81-08-06	12,000
210,212 214,215	ME	Pretest Subsurface Composite		81-08-06	1,060
217,219 221, 223	MC	Post-test Surface Composite		81-08-06	28,000
218, 220 222, 224	MC	Post-test Subsurface Composite		81-08-06	10,000
226, 228 230, 232	ME	Post-test Surface Composite		81-08-06	21,000
227, 229 231, 233	ME	Post-test Subsurface Composite		81-08-06	290
120, 122 124, 126	D(E)C	Pretest Surface Composite		81-08-07	25,000
121, 123 125, 127	D(E)C	Pretest Subsurface Composite		81-08-07	305
129, 131 133, 135	D(E)E	Pretest Surface Composite		81-08-07	24,000
130, 132 133, 135	D(E)E	Pretest Subsurface Composite		81-08-07	145

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.		DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
138, 140 142, 144	D(E)C	Post-test Surface Composite	81-08-07	6,070
139,141 143, 145	D(E)C	Post-test Subsurface Composite	81-08-07	5,940
147, 149 151, 153	D(E)E	Post-test Surface Composite	81-08-07	20,000
148, 150 152, 154	D(E)E	Post-test Subsurface Composite	81-08-07	513
300, 302 304, 306	SC	Pretest Surface Composite	81-08-07	14,000
301, 303 305, 307	SC	Pretest Subsurface Composite	81-08-07	370
309, 311 313, 315	SE	Pretest Surface Composite	81-08-07	19,000
310, 312 314, 316	SE	Pretest Subsurface Composite	81-08-07	260
318	SC	Surface Post-test Slow XL Not Raked	81-08-07	23,000
319	SC	Subsurface Post-test Slow XL Not Raked	81-08-07	40,000
325	SC	Subsurface Post-test Fast XL Raked	81-08-07	440
328,330 332, 334	SE	Subsurface Post-test Composite Fast XL Raked	81-08-07	230
400, 402 404, 406	D(B)C	Pretest Surface Composite	81-08-07	4,310
409, 411 413, 415	D(B)E	Pretest Surface Composite	81-08-07	7,370
410, 412 414, 416	D(B)E	Pretest Subsurface Composite	81-08-07	70
418, 420 422, 424	D(B)C	Post-test Surface Composite	81-08-07	10,000
419, 421 423, 425	D(B)C	Post-test Subsurface Composite	81-08-07	3,130

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.		DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
427, 429 431, 433	D(B)E	Post-test Surface Composite	81-08-07	2,740
428, 430 432, 434	D(B)E	Post-test Subsurface Composite	81-08-07	4,400
156, 158 160, 162	D(E)C	Surface Composite (+ 8 day)	81-08-14	440
157, 159 161, 163	D(E)C	Subsurface Composite (+ 8 day)	81-08-14	2,390
165, 167 169, 171	D(E)E	Surface Composite (+ 8 day)	81-08-14	2,370
166, 168 170, 172	D(E)E	Subsurface Composite (+ 8 day)	81-08-14	290
235, 237 239, 241	MC	Surface Composite (+ 8 day)	81-08-14	4,980
236, 238 240, 242	MC	Subsurface Composite (+ 8 day)	81-08-14	16,000
244, 246 248, 250	ME	Surface Composite (+ 8 day)	81-08-14	19,000
245, 247 249, 251	ME	Subsurface Composite (+ 8 day)	81-08-14	310
271, 273 275, 277	CC	Surface Composite (+ 8 day)	81-08-14	17,000
272, 274 276, 278	CC	Subsurface Composite (+ 8 day)	81-08-14	1,500
281, 283 285, 287	CE	Subsurface Composite (+ 8 day)	81-08-14	380
336	SC	A1 Surface (+ 8 day)	81-08-15	300 (1760)

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.		DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
337	SC	A1 Subsurface (+ 8 day)	81-08-15	5,640 (4,930)
338 340	SC	Surface Composite (+ 8 day)	81-08-15	1,790
339 341	SC	Subsurface Composite (+ 8 day)	81-08-15	6,670
342	SC	Surface B8 (+ 8 day)	81-08-15	3,170
343	SC	Subsurface B8 (+ 8 day)	81-08-15	730
436, 438 440, 442	D(B)C	Surface Composite (+ 8 day)	81-08-15	trace
437, 439 441, 443	D(B)C	Subsurface Composite (+ 8 day)	81-08-15	3,190
445, 447 449, 451a	D(B)E	Surface Composite (+ 8 day)	81-08-15	70
446, 448 450, 451b	D(B)E	Subsurface Composite (+ 8 day)	81-08-15	80
174, 176 178, 180	D(E)C	Surface Composite (+ 40 day)	81-09-16	360
175, 177 179, 181	D(E)C	Subsurface Composite (+ 40 day)	81-09-16	170
183, 185 187, 190	D(E)E	Surface Composite (+ 40 day)	81-09-16	330
184, 186 191, 189	D(E)E	Subsurface Composite (+ 40 day)	81-09-16	trace
253, 255 257, 259	MC	Surface Composite (+ 41 day)	81-09-16	19,000
254, 256 258, 260	MC	Subsurface Composite (+ 41 day)	81-09-16	1,880
262, 264 266, 268	ME	Surface Composite (+ 41 day)	81-09-16	1,890

APPENDIX C: SHORELINE SPILLS: TOTAL HYDROCARBONS IN BEACH SEDIMENT (continued)

SAMPLE I.D.		DESCRIPTION	DATE SAMPLED	RESULT (mg/kg)
263, 265 267, 269	ME	Subsurface Composite (+ 41 day)	81-09-16	190
289, 291 293, 295	CC	Surface Composite (+ 41 day)	81-09-16	3,110
290, 292 294, 296	CC	Subsurface Composite (+ 41 day)	81-09-16	150
298, 2001 2003, 2005	CE	Surface Composite (+ 41 day)	81-09-16	930
299, 2002 2004, 2006	CE	Subsurface Composite (+ 41 day)	81-09-16	110
354	SC	B1 Surface (+ 40 day)	81-09-16	5,440
355	SC	B1 Subsurface (+ 40 day)	81-09-16	3,700
356 358	SC	Surface Composite (+ 40 day)	81-09-16	32,000
357 359	SC	Subsurface Composite (+ 40 day)	81-09-16	2,190
453, 455 457, 459	D(B)C	Surface Composite (+ 40 day)	81-09-16	trace
454, 456 458, 460	D(B)C	Subsurface Composite (+ 40 day)	81-09-16	trace
462, 464 466, 468	D(B)E	Surface Composite (+ 40 day)	81-09-16	trace
463, 465 467, 469	D(B)E	Subsurface Composite (+ 40 day)	81-09-16	trace